York Mills Collegiate Institute

Physics!

SPH3U
Course Notes
Spring 2013

Student Name:
Gr. 11 Physics Syllabus

This chart contains a complete list of the lessons and homework for Gr. 11 Physics. Please complete all the Textings and problems listed under “Homework” before the next class. A set of optional online resources, lessons and videos is also listed under “Homework” and can easily be accessed through the links on the Syllabus found on the course webpage (http://abelmoodle.abel.yorku.ca/moodle/course/view.php?id=388. It’s called “York Mills – Physics 11”). You may want to bookmark or download the syllabus for frequent use.

The textbook reading are divided up into small parts (often a single paragraph) and don’t follow the order in the class very closely. You may want to take notes from these sections, but this is not necessary since all the content is in your handbook or is discussed in class.

Some of the video lessons listed are from the website “Khan Academy”, www.khanacademy.org which has many math and physics lessons. Another excellent source of online lessons comes from the physics teachers at Earl Haig S. S. http://www.physicseh.com/. One warning: Sometimes the notation used in the online lessons is different from what we use in class. Please be sure to use our notation. The Physics Classroom (http://www.physicsclassroom.com) is another excellent website, but does include more advanced material as well.

### Introduction

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### Kinematics

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<td>Position graphs for uniform / nonuniform motion</td>
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<td>Interpreting Position Graphs</td>
<td>Displacement, velocity vs. speed, when is v changing?</td>
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<td>4</td>
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<td>Problem solving, units and conversions</td>
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<td>6</td>
<td>Changing Velocity</td>
<td>Changing speed Handbook: Representations of Motion</td>
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<td>Changing Velocity, continued</td>
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<td>8</td>
<td>The Idea of Acceleration</td>
<td>Acceleration, slope of v-t graph</td>
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(Note: there are MANY errors in the narration, but the footage is excellent)

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<td>Calculating Acceleration</td>
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<td>Speeding Up or Slowing Down?</td>
<td>Sign of the acceleration, speeding up, slowing down, representations of SD &amp; SU in d-t and v-t graphs,</td>
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<td>Area and Average Velocity</td>
<td>area under v-t graph, sudden changes in motion, average velocity</td>
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<td>The Displacement Problem</td>
<td>Calculating displacement for uniform acceleration</td>
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<td>The BIG Five</td>
<td>The BIG 5 equations, multiple representations of motion, problem solving</td>
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<td>Freefall</td>
<td>Vertical motion, freefall, turning around</td>
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<td>16</td>
<td>Acceleration of Gravity</td>
<td>ag, freefall problem solving, multiple solutions, distance</td>
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<td>17</td>
<td>Cart Project</td>
<td>Review: pg. 52 #5, 6, 20, 23, 28, 29, pg. 88 #14, 16</td>
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<td>Review: Graphing Summary</td>
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### 2-D Motion

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<tbody>
<tr>
<td>1</td>
<td>Two Dimensional Motion</td>
<td>Displacement vectors in 2-D, scale vector diagrams, distance vs. displacement, speed vs. velocity</td>
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<td>2</td>
<td>Vector Adventure</td>
<td>Adding vectors</td>
</tr>
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<td>3</td>
<td>Relative Velocity</td>
<td>Relative velocity, addition of velocity vectors</td>
</tr>
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<td>4</td>
<td>Relative Velocity, continued</td>
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<tr>
<td>5</td>
<td>Quiz on 2-D motion</td>
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### Forces

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<th>Lesson</th>
<th>Topic</th>
<th>Notes</th>
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<tr>
<td>1</td>
<td>What is a Force?</td>
<td>Idea of force, interactions</td>
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<td>2</td>
<td>What is the Effect of a Force?</td>
<td>Force causes acceleration</td>
</tr>
<tr>
<td>4</td>
<td>The Inertia Principle</td>
<td>Systems, inertia, changing forces</td>
</tr>
</tbody>
</table>
## Lesson: First Law
Video: Forces in Space!

5 The Force of Gravity
Force of gravity, gravitational field strength, \( F_g = mg \)
Read: “Gravitational Field Intensity”, pg. 71-5
Problems: pg. 72 #1, 2, pg. 74 #2, pg. 76 #3
Video: Big Bang Theory
Video: Gravity – Newton to Einstein

6 Normal Force
Normal force
Read: “Normal Force”, pg. 94
Handbook: Normal Forces
Lesson: Normal Force
Video: Normal Force

7 Force, Mass and Motion
Force and mass affect acceleration
Video: Cars and Inertia
Handbook: Representing Forces

8 Force, Mass and Motion – part 2
Newton’s 2nd law, \( F_{\text{net}} = ma \), definition of force, definition of Newton, inertia
Read: “Newton’s Second Law”, pg. 106-8
Problems: pg. 114 #5-7
Lesson: Newton’s Second Law
Video: 2nd Law in Space!

9 Newton’s Second Law
Problem Solving
Force problem solving techniques
Problems: finish handbook questions and pg. 112 #1, pg. 114 #8
Lesson: Finding the Net Force
Video: Misconceptions About Freefall

10 Forces as Interactions
Forces are interactions
Video: 3rd Law in Space!
Video: Newton’s Third Law

11 Newton’s 3rd Law
Newton’s 3rd Law, Force pairs
Read: “Newton’s 3rd Law”, pg. 114-6
Handbook: Newton’s Third Law (pg. 94)

12 Friction
Kinetic and static friction
Read: “Kinds of Friction”, pg. 92-7
Video: Brake Test
Video: Chevy Volt Test

13 Friction
Coefficient of friction, \( F_t = \mu F_n \)
Problems: pg 96 #1, 2, pg. 97#1, 2, pg. 122 #1, 123#2
Lesson: Static and Kinetic Friction
Lesson: Intro to Friction
Lesson: Friction Problem

14 Review
Problems: pg. 124 #3, pg 130 #5, 8, 15, pg. 136 #8, 12, 14, 45, 47, 51
Review: Newton’s Laws

15 Test

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### Energy

1 The Flow of Energy
Energy flow diagrams, bar charts
Lesson: Energy Diagrams

2 Doing Work!
Positive, negative work, net work-kinetic energy theorem
Read: “Conditions for Mechanical Work”, pg. 144-6
Problems: pg. 146 #1, 2, pg. 151 #3, 4
Lesson: Work and Energy

3 Measuring Energy
Kinetic energy, gravitational potential energy
Read: “Kinetic Energy”, pg. 162-6
Problems: pg. 164 #1, 2, pg. 166 #5
Lesson: Work and GPE
Video: Swinging Ball of Death

4 Gravitational Potential Energy
Path independence, vertical origin
Read: “Changes in Gravitational Energy”, pg. 159-60
Problems: pg. 160 #2, pg. 161 #4

5 The Conservation of Energy
Conservation of energy, thermal energy
Read: “Energy and Its Characteristics”, pg. 152
Problems: pg. 170 #1, 2, pg. 172 #5, 6
Lesson: Conservation Problems
Video: Canada’s Wonderland Behemoth
Simulation: Rollercoaster
Simulation: Skateboarding Park

6 Power
Definition of power, watt
Read: “Power”, pg. 188-9
Problems: pg. 189 #1, 2

7 Review Lesson
Review: pg. 232 #43a, 49, 53, 54
Video: The Most Important Video You Will Ever See
### Waves and Sound

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<tbody>
<tr>
<td>1</td>
<td>Quiz on Energy Good Vibrations</td>
<td>Periodic motion, types of vibrations, frequency, period, amplitude, displacement, phase</td>
<td>E-Book: The Physics of Music</td>
</tr>
<tr>
<td>2</td>
<td>Good Vibrations, continued</td>
<td>Read: Characteristics of Vibrations, pg. 238-40 Problems: pg. 240 #3-5</td>
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<tr>
<td>3</td>
<td>Properties of the Pendulum</td>
<td>Read: Infobit, pg. 82-3 Do not memorize the pendulum equation!</td>
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<tr>
<td>4</td>
<td>Making Waves</td>
<td>Read: Transverse Waves, pg. 244-5 Problems: pg. 246 #3, 4a Lesson: Intro to Waves Video: Types of Waves Simulation: Transverse Waves</td>
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<td>5</td>
<td>Making Waves, continued Interference</td>
<td>Read: Wave Behaviour, pg. 251-3 Problems: pg. 257 #2, 3, 5 Video: Two Pulses Interfering</td>
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<td>6</td>
<td>The Speed of Waves</td>
<td>Read: The Speed of Waves, pg. 247-8 Problems: pg. 251 #1-5 Video: T, F, and v</td>
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<td>7</td>
<td>Standing Waves</td>
<td>Read: Mechanical Resonance, pg. 241-2 Read: Standing Waves, pg. 292-3 Lesson: Standing Waves Video: Standing Waves Video: Shatter Glass Video: Shatter Glass</td>
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<td>8</td>
<td>Sound Waves</td>
<td>Read: Longitudinal Waves, pg. 245-6 Simulation: Sound Waves</td>
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<td>9</td>
<td>The Propagation of Sound</td>
<td>Speed of sound Read: Speed of Sound, pg. 277 Problems: pg. 277 #1, 2, pg. 279 #2</td>
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<td>10</td>
<td>The Interference of Sound</td>
<td>Interference of sound waves, beat frequency, Loudness, pitch, intensity, timbre, waveform Read: The Interference of Sound, pg. 281-2 Problems: pg. 282 #1, 2 Read: The Characteristics of Sound, pg. 268-9 Read: Hearing Sound, pg. 271 Simulation: Complex Waves</td>
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<td>11</td>
<td>The Vibrating String</td>
<td>Frequency dependence on length, tension, harmonic series Read: Stringed Instruments, pg. 297-8 Problems: pg. 298 #1, 2, pg. 270 #4, pg. 276 #2</td>
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<td>12</td>
<td>Resonance in Air Columns</td>
<td>Open and closed air columns, resonant length, resonant frequency Read: Acoustical Resonance in Air Columns, pg. 300-5 Problems: pg. 306 #1-5 Lesson: Air Columns</td>
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<td>14</td>
<td>Waves and Sound Problem Solving</td>
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<td>15</td>
<td>Test</td>
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### Electricity

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<td>The Flow of Electricity</td>
<td>Circuits, conductors, insulators, electric current, ammeters</td>
<td>Problems: pg. 457 #1a, 2b Read: Electric Current, pg. 455-8 Simulation: Electric Circuits Lab</td>
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<td>Electric Circuits and Voltage</td>
<td>Circuit diagrams, batteries, electric potential difference, voltage, voltmeters, voltage rise, voltage drop, sources, loads</td>
<td>Problems: pg. 464 #1, 2, pg. 468 #4a,c Read: Electric Potential Difference, pg. 460-2 and 464-5 Read: Circuit Diagrams, pg. 466 Video: Current and Voltage</td>
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<td>Bulbs in Series</td>
<td>Series circuits, current model, resistance, resistance in series,</td>
<td>Simulation: Battery-Resistor Circuit Video: Dr. Megavolt</td>
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<td><strong>4</strong></td>
<td>Bulbs in Parallel</td>
<td>Parallel circuits, resistance in parallel, current rule</td>
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<td>Handbook: <em>Bulbs in Parallel Homework</em></td>
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<td>A Complex Circuit</td>
<td>Current rule, voltage rule</td>
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<td>Handbook: <em>A Complex Circuit Homework</em></td>
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<td>Resistance and Ohm’s Law</td>
<td>Ohm’s law, definition of resistance, equivalent resistance in series and parallel</td>
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<td>Problems: pg. 494 #4, 10a, b</td>
<td>Read: Resistance and Ohm’s Law, pg. 486-8</td>
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<td>Read: Resistors in Series and Parallel, pg. 495-9</td>
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<td>Lesson: <em>Resistors in Parallel</em></td>
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<td>Simulation: <em>Ohm’s Law</em></td>
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<td>Circuit decomposition</td>
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<td>Handbook: <em>Electrical Connections</em></td>
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<td>Read: Series-Parallel Combinations of Resistors, pg. 502-4</td>
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<td>Circuit Analysis</td>
<td>Circuit analysis</td>
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<td>Review: <em>Electric Circuits</em></td>
<td>Electricity Review: pg. 482 #2-4, 20, 23, pg. 516 #3, 7, 8, 14,</td>
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An Inquiry-Based Course
Welcome to the wonderful world of physics! SPH3U is an introduction to the world of physics and a prerequisite for the grade 12 course, SPH4U. This course is designed according to the principles of Physics Education Research (see http://www.compadre.org/PER/) which clearly demonstrate the power of learning through inquiry in a collaborative group format. Major Canadian and American universities (U of T, McGill, McMaster, MIT, Harvard, Stanford and more) are transforming their introductory physics courses by reducing or eliminating traditional lectures and replacing them with engaging activities that have a deep conceptual and practical focus.

U of T: http://www.upscale.utoronto.ca/Practicals/Overview/Overview.html
Harvard: http://youtu.be/WwslBPj8GgI

Text reading, Note-Taking and Homework
In Grade 11 physics, students will spend the majority of class time doing activities and discussing physics. To accommodate this, students are required to do textbook readings. In class, we will briefly clarify and amplify the text before returning to the activities and discussions. In addition to the readings, you will also have problems to solve as part of your homework. On average you will have about 30 minutes of homework each day. Your homework will be randomly checked for completion. Optional online lessons and resources are listed for each lesson.

Assessment and Evaluation
Due to the central role of group work in this course, the work you do in groups will account for an important portion of your mark. Daily group work will be randomly handed-in and marked. To help ensure that individual students are pulling their weight in groups, there will be regular quizzes based directly on group work. A bonus will be given to groups whose members all score at least 75%.
The content from your group work and home study will, of course, also appear on tests. There will be regular tests that survey each unit of our physics course. There is a final exam that covers the course's entire material and a few small projects that will be announced throughout the course.

**Mark Breakdown**
The categories of *Knowledge and Understanding*, *Thinking*, *Communication*, and *Application* are a component of most of the evaluation tools used in this course – however some focus on certain categories more than others. The basic mark breakdown for the course is 70% term work and 30% final examination. The term mark is composed approximately as follows:

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<th>Category</th>
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<tr>
<td>Knowledge and Understanding</td>
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<tr>
<td>Thinking</td>
<td>14%</td>
</tr>
<tr>
<td>Communication</td>
<td>14%</td>
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<tr>
<td>Application</td>
<td>14%</td>
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<table>
<thead>
<tr>
<th>Category</th>
<th>Weight</th>
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</thead>
<tbody>
<tr>
<td>Tests</td>
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<tr>
<td>Daily group work (7%) and Group work quizzes (7%)</td>
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<tr>
<td>Tests (8%) and Note or Homework Checks (6%)</td>
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<tr>
<td>Projects</td>
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</table>

**Attendance and Punctuality**
Most of your work takes place in groups and by being either absent or late you handicap yourself and your group. Students are responsible for determining what was missed and making sure that they are caught up *before* the following class – exchange phone numbers and consult your group members as your first step. Any evaluations of group work a student is absent for will be awarded a zero unless a valid reason with appropriate documentation is presented when the student returns to school.

**Missed Tests**
If you miss a test you **must**:
- Let me know in advance if it is due to a pre-arranged reason (i.e. appointment for surgery)
- Call in to the school so your name goes on the daily “Absent List” in the main office.
- Contact your teacher immediately after setting foot in the school upon your return.
- Provide a doctor's note if the reason is illness.
- Do not discuss the test by any means with your colleagues.
- Be prepared to write the test immediately, at your teacher’s discretion.

Failure to do any of these will result in a zero for that evaluation.

**Please Read This!**
Please sign below signifying that you have read this course introduction.

__________________________________
Signature of parent, or student if 18 and over

__________________________________
Print name
The course website is an electronic extension of our classroom. Your behaviour and conduct on the site should adhere to the same standards of our physical, Gr. 11 classroom. To enrol in the course website, please follow these instructions and use the enrolment key shown below.

1. Go to the website: http://abelmoodle.abel.yorku.ca
2. On the right side of the page click on the “Create new account” button below the login button.
3. Use your regular first name followed by your last name for your user name (for example johnsmith for John Smith). Choose any appropriate password. Remember your password!!
4. Type in a valid email address, which you will be able to hide later if you go in and edit your profile. Enter your first name and last name in the appropriate fields. Follow the rest of the instructions for logging in.
5. A message will be sent to your e-mail address. Follow the instructions in this message to validate your account.
6. Go back to the website: http://abelmoodle.abel.yorku.ca and login with your username and password.
7. Once you have access to the list of courses click on the Toronto District School Board science category and your course is called: York Mills 11 Physics. Click on the course name.
8. Type your enrollment key in the text box. The enrollment key to get in is: ym11physics
9. Explore the site and see what it has to offer. A good place to start is to edit your profile. To edit your profile, click on your name in the top right corner of the main page and then click on the “Edit profile” tab. Once you have completed all the required fields, click on the “Update profile” button at the bottom of the page.
Each group needs a whiteboard, marker and cloth. Assign each group member one role: **Manager, Recorder, or Speaker.** If there are four people in a group, two will act as the speaker. Working well in a group is a bit like acting in a play, we all have roles to perform!

**Manager:** *Ask the group members to read the following instructions for this activity.*

The majority of our work in Gr. 11 physics will take place in groups. Take a few moments to think about our experiences of working in groups. Think about your experiences in other courses and your experience so far in Gr. 11 physics. We will discuss these experiences, but please don’t mention anyone’s name!

**Manager:** *Ask the group to complete the next two questions individually, without any discussion. When you see that everyone has finished, have the group move on.*

Complete the following two questions individually.

1. In your experience, what are some of the enjoyable characteristics of working in groups?

2. In your experience, what are some of the less-enjoyable characteristics of working in groups?

Work together now. On your whiteboard compile a list of the group’s responses to each question.

**Manager:** *Organize the discussion and ask for ideas from each group member.*

**Recorder:** *Neatly summarize the ideas on the whiteboard, write large enough so other groups could read it if you were to hold it up.*

**Speaker:** *Be prepared to speak to the class about your points when your group is called upon – if any points are unclear, ask your group questions.*

Continue the following questions as a group.

**Manager:** *Read out the next question and ask the group for their ideas. Kindly ask everyone for their input.*

**Recorder:** *Make sure what you write down on your own sheet accurately represents the group’s ideas – your teacher will be checking your copy. Ask the other members for clarification if you’re not sure you have it right.*

**Speaker:** *Be prepared to speak on behalf of the group. If any ideas are not clear, ask the others for an explanation or ask specific questions. Make sure the group explanations would receive a mark of “5” – are they thorough and complete?*

We have all experienced difficulties working in groups. Sometimes, the challenge comes from within – for whatever reason you, as an individual, are unable to contribute effectively to the group. Other times, another group member may make the proper functioning of the group difficult.
3. Think about the reasons why a group might not function at its best. Make a list of the reasons in the chart below – be specific. However, do not mention the names of any individuals. This is not a critique of your current group or any others you have been in.

<table>
<thead>
<tr>
<th>Reason Groups Might Not Work Well</th>
<th>Actions</th>
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<tbody>
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<td>1.</td>
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<td>2.</td>
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<td>3.</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
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</tbody>
</table>

4. Describe what specific actions could be taken to help the group work better in each case you listed above. Indicate which group member (R, M, S) would be best to carry out the action, or if it is an action for everyone (E).

Check your results with your teacher.

Manager: When the group decides it had finished question 4, call the teacher over. Keep an eye on the clock since we want to complete the whole activity in this period.

Recorder: The teacher will ask you to write up one example on the whiteboard for a class discussion. Have the others check this.

Speaker: Be prepared to speak on behalf of your group when called upon. Make sure the action is clear and precise.

Manager: Lead the group through the next question.

5. Begin by working individually on the next question. In the chart below, list the responsibilities of your role in the group. When everyone is complete, share and discuss the results. Finally, complete the rest of the chart.

<table>
<thead>
<tr>
<th>Manager</th>
<th>Recorder</th>
<th>Speaker</th>
</tr>
</thead>
</table>

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SPH4U: Homework – How Groups Work

On the course website are two videos which chronicle the exploits of a dysfunction physics group and a well-functioning physics group. Begin by viewing the video of the dysfunctional group.

A: Dysfunctional Group

1. Observe. Watch the video and note in the chart below any actions or behaviours of Sam, Robert or Mike that contribute to the poor functioning of the group.

<table>
<thead>
<tr>
<th></th>
<th>Sam</th>
<th>Robert</th>
<th>Mike</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

2. Reflect. The video is something of an exaggeration, but it does help us to think about our own behaviours. Which individual(s) do you think you share the most habits with? (Of course you won’t be as extreme as these guys, but maybe you have a tendency to do some of the same things? Be honest!) Explain.

3. Reason. Imagine you were a well-function member of this group. Describe some actions you would have taken to help the group work better (i.e. to help smooth over some of the problems you mentioned above).

B: The Well-Functioning Group

1. Observe. Watch the video of the well-functioning group. Record in the chart below the positive behaviors of Sam, Robert and Mike which help the group to function well.

<table>
<thead>
<tr>
<th></th>
<th>Sam</th>
<th>Robert</th>
<th>Mike</th>
</tr>
</thead>
<tbody>
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<td></td>
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</table>

2. Reflect. Which of the behaviours that you mentioned in the previous question do you think you share with Sam, Robert or Mike? Explain.

3. Reflect. Which of the behaviours that you noted in question B#1 would you like to encourage more of in yourself? How can you do this?
A: The Physics Road Trip
You decide to take a trip to hear a lecture by one of your favourite physicists. When you begin driving, you glance at the clock in your car and also look at the odometer. As you pull in to the physics department parking lot, you look at the clock and the odometer a second time.

1. How much time did the trip take in minutes?

2. We would like to change this time interval into seconds. Explain how to do this conversion and then show the math.

3. Think carefully about your result in seconds - how many of the digits do you think are reliable or significant? Remember that the measurement device only measures to the nearest minute. Rewrite your answer if necessary.

4. What distance, in kilometers, did you travel?

5. We would like to change this distance into metres. Explain how to do this conversion, then show the math.

6. Think carefully about your distance in metres – explain how many significant figures your result should have. Rewrite your answer if necessary.

7. Calculate your average speed (average speed = distance traveled / time interval) during this trip twice – first, to get an answer in kilometers per hour and second, to get an answer in metres per second.

<table>
<thead>
<tr>
<th>kilometers per hour</th>
<th>metres per second</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

**General Guideline for Significant Figures:** When performing calculations, write the intermediate results with one extra significant figure and the final answer with no more significant figures than the piece of data with the least. This is a handy but very approximate rule of thumb. In university you will learn a mathematical system for determining the error in your calculated results which will replace this handy rule.

8. Explain how many significant figures each final answer should have.
Measurements are the backbone of all science. Any scientific ideas, no matter how slick, are only as good as the measurements that have confirmed them. Without careful measurements, science is mostly guess work and hunches – suspicions and rumours.

A. The Meter Stick

The most basic scientific tool is the meter stick. But, do you know how to use it? For this investigation you will need one meter stick

1. Examine the markings on the meter stick. What is the size of the smallest interval marked on it?

2. Three students use the meter stick to measure the height of a desk and each reports their results: 95 cm, 94.8 cm, and 95.03 cm respectively. Considering the intervals marked on the meter stick, which result illustrates the best use of this measuring device? Explain.

The term significant digits describes which digits in a number or measurement are physically meaningful or reliable.

3. How many significant digits are in the measurement you chose in question A#2?

4. Measure the height of your desk and record the measurement with an appropriate number of significant digits.

5. Two students each measure the length of a running shoe. One student records a result of “285”. The other student measures the same shoe and records the result “27.9”. How can two measurements of the same thing be so different … or are they? Explain by describing what critical element is missing from each measurement.

6. Two students make a measurement using the metre stick. One student measures the thickness of a text book to be 5.1 cm (biology!) The other student measures the length of a pencil to be 18.4 cm. Which measurement is more precise? Offer an explanation and mention what you think the word precision means.
B. The Stopwatch

Now we will examine another common measuring device. You will need one stopwatch.

A student drops a pencil from a 1.00 m height. Another student times the fall. The stopwatch readout looks like this after the timing:

0:00.45

1. Write this reading as a number in decimal notation (not scientific notation) with units of seconds (s).

2. What is the precision of the stopwatch according to its display (i.e. to the nearest …)?

3. Perform the measurement four times, record the times below and calculate an average time.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>Avg:</th>
</tr>
</thead>
</table>

4. How many significant digits are reasonable to use when writing down the calculated average? Explain.

General Guideline for Significant Digits: When performing calculations, write the intermediate results with one extra digit and the final answer with no more significant digits than the piece of data with the least. This is a handy but very approximate rule of thumb. In university you will learn a mathematical system for determining the error in your calculated results which will replace this handy rule.

In traditional decimal notation, there can be some ambiguity about the number of significant digits a measurement has. Use scientific notation for clarity (only showing the significant digits) or for convenience (very large or small numbers). Never write down all the digits your calculator computes – they are not always significant!

5. The whole class times how long it takes one student to run from the class, down to the YM snack stand and back, simply by observing the classroom clock. The computed average of the class measurements is 78.6176548 s. Explain how to write this calculator result in an appropriate way.
SPH3U: How to Answer a Question?

A major focus of Gr. 11 physics is the careful explanation of our observations and ideas. Every word question you encounter should be carefully explained using complete sentences and correct English. Even if the question doesn’t actually say “explain”, you must still justify your answers and outline your reasoning.

A: Evaluation of Daily Work in Physics

Each day one or two groups at random will be selected to submit their work. Please staple each group member’s copy together with the recorder’s copy on the top. The recorder’s copy will be marked in detail – please refer to it for feedback. The manager’s and speakers copy will be marked briefly with only a small amount of feedback. The work by each member of a well-functioning group should be of comparable quality and will usually receive the same grade. When there is an obvious difference in quality, different marks will be assigned. Very high quality work is expected in physics. The final mark will usually be the lowest of the three categories described in the rubric below.

Language

0-2 Numerous errors to the point of distraction. Largely unintelligible. Fragmented.
3 Understandable, but messy or fragmented. Many spelling or grammatical errors.
4 Neat with complete sentences. Few spelling mistakes or errors in grammar. Clearly worded or phrased.

Mathematics

0-2 Numerous errors or omissions.
3 Most work is correct. Units or important steps are routinely missing.
4 Work is correct. Units and steps are shown. Only minor errors or omissions.
5 Work is correct and would be easily understood by a non-physics student. Units are shown. Algebraic steps are carefully shown or process is explained. Essentially no errors.

Physics

0-2 Clear difficulties with key physics ideas.
3 Main physics ideas are correct, but important details may not be. Explanations are brief and possibly incomplete or incorrect.
4 Main physics ideas are correct. Explanations are complete and clear. Difficulties with minor details.
5 Physics ideas are correct and thoroughly explained. Explanations explicitly refer to observations or physical laws and principles. Ideas are explained using multiple representations. Insight and higher-level thinking is demonstrated.

B: Evaluate These Responses!

Evaluate the four student responses below to question A#6 from yesterday’s activity.

Response 1: The second measurement is more precise. It has three significant figures but the first one only has two. Precision is the number of significant figures, so the more significant figures a measurement has, the more precise it is.

0 1 2 3 4 5 because

Response 2: The measurements are equally precise since they are both accurate to one millimeter, which is the smallest unit indicated on the metre stick. The smallest unit is what precision refers to.

0 1 2 3 4 5 because

Response 3: Precision means how careful the measurement is done and there were no mistakes. Both measurements were careful to the one millimeter so they are equally good.

0 1 2 3 4 5 because

Response 4: Precision describes the smallest unit of measurement or interval that the measurement device can distinguish. Both objects were measured in the same way with the same device and must have the same precision, which in this case happens to be to the nearest millimeter. The number of significant figures of the measurements (two and three) is not the same things as precision.

0 1 2 3 4 5 because

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SPH3U: Introduction to Motion

Welcome to the study of physics! As young physicists you will be making measurements and observations, looking for patterns, and developing theories that help us to describe how our universe works. The simplest measurements to make are position and time measurements which form the basis for the study of motion.

A: Constant Speed?
You will need a motorized physics buggy, a pull-back car, a large measuring tape and a stopwatch.

1. Observe. Which object moves in the steadiest manner: the buggy or the pull-back car? What observations allow you to decide?

2. Reason. Excitedly, you show the buggy to a friend and mention how its motion is very steady or uniform. Your friend, for some reason, is sceptical. Describe how you could use some simple distance and time measurements (don’t do them!) which would convince your friend that the motion of the buggy is indeed very steady.

3. Define. The buggy moves with constant speed. Use your ideas from the previous question to help write a definition for constant speed. (Danger! Do not use the words speed or velocity in your definition!) When you’re done, write this on your whiteboard – you will share this later.

Definition: Constant Speed

B: Testing an Hypothesis – Constant Speed
Your challenge is to test the hypothesis that “the buggy moves with a constant speed”. Use a physics buggy, large measuring tape and stopwatch (or your smartphone with lap timer!). We will make use of a new idea called position.

To describe the position of an object along a line we need to know the distance of the object from a reference point, or origin, on that line and which direction it is in. Usually the position of an object along a line is positive along one side of the origin of the origin and negative if it lies on the other – but this sign convention is really a matter of choice. Choose your sign convention such that the position measurements you make today will be positive.

1. Plan. Discuss with your group a process that will allow you test the hypothesis mentioned above. Draw a simple picture, including the origin, and illustrate the quantities to be measured. Describe this process as the procedure for your experiment.
2. **Discuss.** On a whiteboard, use a picture and short descriptions to summarize your experimental process. We will discuss this as a class before moving on.

3. **Measure.** Push in your stools and conduct your experiment. Record your data below.

<table>
<thead>
<tr>
<th>Position (m)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **Reason.** Explain how you can tell just by looking at the data if the speed is constant.

5. **Represent.** How can you represent the motion of your buggy using a line and dots? Imagine your buggy draws a dot on the ground for every second that it moves. Show this on the axis below (your choice of scale is not important). Note that the vertical line on the left hand side is the origin and the arrow points in the positive direction. Explain how you chose to draw your dots. This type of representation is called a *motion diagram*.

![motion diagram]

6. **Represent.** Now plot your data on a graph. Make the following plot: position (vertical) versus time (horizontal).

7. **Find a pattern.** When analyzing data, we need to decide what type of pattern the data best fits. Do you believe the data follows a curving pattern or a straight-line pattern? Why do you think the data does not form a perfectly straight line? Explain.

![graph]

**Line of Best-Fit.** The purpose of a line of best fit is to highlight a pattern that we believe exists in the data. Real data always contains errors which lead to *scatter* (wiggle) amongst the data points. A best-fit line helps to average out this scatter and error. Any useful calculations made from a graph should be based on the best-fit line and **not** on the data chart or individual points. As a result, we never connect the dots in our graphs of data.

8. **Reason.** Imagine an experiment with a different buggy that produced a similar graph, but with a steeper line of best fit. What does this tell us about that buggy? Explain.
9. **Calculate and Interpret.** Calculate the slope of the graph (using the best-fit line, don’t forget the units). Interpret the meaning of the slope of a position-time graph. (What does this quantity tell us about the object?) **Reminder:** \( \text{slope} = \frac{\text{rise}}{\text{run}} \).

10. **Explain.** Explain how you could predict (without using a graph) where would the ball be found 1.0 s after your last measurement.

---

**C: The Buggy Challenge**

1. **Predict.** Ask your teacher for your group’s distance. Your challenge is to use your knowledge of motion and predict how much time it will take for your buggy to travel that distance.

2. **Test and Explain.** Set up your buggy to travel the predicted distance and have your stopwatch ready. Call your teacher over to witness your test. Record your results and explain whether your measurements confirm your prediction.

3. **Predict.** Find a group that has a buggy with a fairly different speed than your group’s buggy. Record that speed and return to your group. You will set up the two buggies such that they are initially 3.0 m apart. They will both be released at the same time and travel towards one another. Predict how far your buggy will travel before the two buggies meet!

4. **Test.** Set up the situation for the meeting buggies, call over your teacher, and test it out!
1. A good **operational definition** provides the criteria, or the test, necessary to decide whether some property exists. For example, a student is a “Titan” (a York Mills student) if he or she has a timetable for classes at York Mills (usually a pink sheet). What is the test that can be used to decide whether an object is moving with a constant speed?

2. An inquisitive student, Albert, has a definition of constant speed: *An object always takes the same amount of time to move 1 m.* Marie says, “I don’t think your definition is careful enough. Let’s say I have a wind-up car and let it go. It travels exactly 1 m before it stops. Each time I wind it up and release it, it travels the 1 m in the same amount of time. Yet, I’m pretty sure it’s not moving with a constant speed.” How should Albert’s definition be modified in light of Marie’s objection? Modify Albert’s definition and explain how it shows that Marie’s situation is **not** an example of constant speed.

3. Two toy cars travel with a constant speed, but start moving at different times. Is it possible for one car to **catch up** to the other? Explain with an example.

4. Imagine a dripping cup of paint is attached to a toy car that travels at a constant speed. The drips fall from the cup on to the ground after **equal intervals of time**. Create a **motion diagram** by drawing the pattern of drips (dots) that the toy car would produce on the axis below. The vertical line at one end of the axis represents the origin (the starting point). Draw a pattern for a fast moving toy car and a slow moving toy car. Explain why you think your motion maps are correct.

5. The diagram below shows a motion diagram produced in a different situation. Study the pattern of dots and decide whether these dots represent motion with constant speed or whether the speed is changing. Explain your decision.

6. Different student groups collect data tracking the motion of different toy cars. Study the charts of data below. Which charts represent the motion of a car with constant speed? Explain how you can tell.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
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<tr>
<td><strong>B</strong></td>
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<tr>
<td><strong>C</strong></td>
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<tr>
<td><strong>D</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Distance (cm)</td>
<td>Time (s)</td>
<td>Distance (cm)</td>
<td>Time (s)</td>
<td>Distance (cm)</td>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>15</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1.2</td>
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<tr>
<td>30</td>
<td>2</td>
<td>10</td>
<td>2.4</td>
<td>0.2</td>
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<tr>
<td>45</td>
<td>3</td>
<td>12</td>
<td>3.6</td>
<td>0.3</td>
</tr>
<tr>
<td>60</td>
<td>4</td>
<td>20</td>
<td>4.8</td>
<td>0.4</td>
</tr>
</tbody>
</table>
1. Emmy walks along an isle in our physics classroom. A motion diagram records her position once every second. Two events, her starting position (1) and her final position (2) are labeled. Use the motion diagram to construct a position time graph – you may use the same scale for the motion diagram as the position axis. Draw a line of best-fit.

2. Use the position-time graph to construct a motion diagram for Isaac’s trip along the hallway from the washroom towards our class. We will set the classroom door as the origin. Label the start (1) and end of the trip (2).

3. Albert and Marie both go for a stroll from the classroom to the cafeteria as shown in the position-time graph to the right. Explain your answer the following questions according to this graph.
   (a) Who leaves the starting point first?
   (b) Who travels faster?
   (c) Who reaches the cafeteria first?
   (d) Draw a motion diagram for both Albert and Marie. Draw the dots for Marie above the line and the dots for Albert below. Label their starting position (1) and their final position (2).

4. Albert and Marie return from the cafeteria as shown in the graph to the right. Explain your answer the following questions according to this graph.
   (a) Who leaves the cafeteria first?
   (b) Who is travelling faster?
   (c) What happens at the moment the lines cross?
   (d) Who returns to the classroom?
   (e) Draw a motion diagram for both Albert and Marie. Label their starting position (1) and their final position (2).
Today you will learn how to relate position-time graphs to the motion they represent. We will do this using a computerized motion sensor. The origin is at the sensor and the direction away from the face of the sensor is set as the positive direction. The line along which the detector measures one-dimensional horizontal motion will be called the \( x \)-axis.

**A: Interpreting Position Graphs**

1. *(Work individually)* For each description of a person’s motion listed below, sketch your prediction for what you think the position-time graph would look like. Use a dashed line for your predictions. Note that in a sketch of a graph we don’t worry about exact values, just the correct general shape. Try not to look at your neighbours predictions, but if you’re not sure how to get started, ask a group member for some help.

   - (a) Standing still, close to the sensor
   - (b) Standing still, far from the sensor
   - (c) Walking slowly away from the sensor at a steady rate.
   - (d) Walking quickly away from the sensor at a steady rate.
   - (e) Walking slowly towards the sensor at a steady rate.
   - (f) Walking quickly towards the sensor at a steady rate.

2. *(Work together)* Compare your predictions with your group members and discuss any differences. Make any changes you feel necessary, along with a simple explanation of the reason for the change.

3. *(As a class)* Your group’s speaker is the official “walker”. The computer will display its results for each situation. Record the computer results on the graphs above using a solid line. Note that we want to smooth out the bumps and jiggles in the computer data which are a result of lumpy clothing, swinging arms, and the natural way our speed changes during our walking stride.

4. *(Work together)* Explain the errors in the following predictions.

<table>
<thead>
<tr>
<th>For situation (a) a student predicts:</th>
<th>For situation (d) the student says: “Look how long the line is – she travels far in a small amount of time. That means she is going fast.”</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

5. Describe the difference between the two graphs made by walking away slowly and quickly.

6. Describe the difference between the two graphs made by walking towards and away from the sensor.

**B: The Position Prediction Challenge**

Now for a challenge! From the description of a set of motions, can you predict a more complicated graph?

*A person starts 2.0 m in front of the sensor and walks away from the sensor slowly and steadily for 6 seconds, stops for 3 seconds, and then walks towards the sensor quickly for 6 seconds.*

1. *(Work individually)* Use a dashed line to sketch your prediction for the position-time graph for this set of motions.

2. *(Work together)* Compare your predictions. Discuss any differences. Don’t make any changes to your prediction.

3. *(As a class)* Compare the computer results with your group’s prediction. Explain any important differences between your personal prediction and the results.
C: Graph Matching

Now for the reverse! To the right is a position-time graph and your challenge is to determine the set of motions which created it.

1. (Work individually) Carefully study the graph above and write down a list of instructions that could describe to someone how to move like the motion in this graph. Use words like fast, slow, towards, away, steady, and standing still. If there are any helpful quantities you can determine, include them.

2. (Work together) Share the set of instructions each member has produced. Do not make any changes to your own instructions. Put together a best attempt from the group to describe this motion. Write up your instructions on the whiteboard to share with the class.

3. (As a class) Observe the results from the computer. Explain any important differences between your predictions and the ones which worked for our “walker”.

D: Exciting Curves

Finally, let’s consider the graph below which curves!

1. Describe how to move to produce this graph – make your best attempt:

2. What is the general difference between motion that produces straight-line position-time graphs and motion that produces curved-line position-time graphs.
**SPH3U: Defining Velocity**

To help us describe motion carefully we have been measuring positions at different moments in time. Now we will put this together and come up with an important new physics idea.

A: Changes in Position - Displacement

The position of an object changes when it moves from one place to another. If we imagine it moving along a straight line that we call the $x$-axis, we can note its two positions with the symbols $x_1$, for the initial position and $x_2$, for the final position.

1. What is the position of $x_1$ and $x_2$ relative to the origin? Don’t forget the sign convention and units!
   \[
   x_1 = \quad x_2 =
   \]

2. Did the object move in the positive or negative direction? How far is the end position from the starting position? Use a ruler and draw an arrow (just above the line) from the point $x_1$ to $x_2$ to represent this change.

The change in position of an object is called its displacement. The displacement can be found from the quantity: $x_2 - x_1$. The Greek letter delta ($\Delta$) means “change in” and always describes a final value minus an initial value. We will notate the change in position, or displacement, as $\Delta x$ (“delta $x$”). The displacement can be represented graphically by an arrow, called the displacement vector, pointing from the initial to the final position. Any quantity in physics that includes a direction is a vector.

3. Calculate the displacement of the object in the example above. Consider your answers to question A#2. What is the interpretation of the number part of the result of your calculation? What is the interpretation of the sign of the result?
   \[
   \Delta x = x_2 - x_1 =
   \]

4. Displacement is a vector quantity. Is position a vector quantity? Explain.

5. Calculate the displacement for the following example. Draw a displacement vector that represents the change in position.

---

Adapted from *Physics by Inquiry*, McDermott and PEG U. Wash, © John Wiley and Sons, 1996
B: Changes in Position and Time

In a previous investigation, we have compared the displacement of the physics buggy with the amount of time taken. These two quantities can create an important ratio.

In uniform motion, the *velocity* of an object is a quantity that describes the displacement that occurs in one unit of time.

1. Write an algebraic equation for the velocity of a uniformly moving object in terms of $v$, $x$, $\Delta x$, $t$ and $\Delta t$. (Note: some of these quantities may not be necessary.)

2. Suppose an object moves with uniform motion from $x_1 = 76 \text{ cm}$ to $x_2 = 13 \text{ cm}$ in a time interval of 0.7 seconds. What is its velocity? Provide an interpretation for the sign of the result.

In physics, there is an important distinction between *velocity* and *speed*. Velocity includes a direction while speed does not. Velocity can be positive or negative, speed is always positive. For **uniform motion only**, the speed is the magnitude (the number part) of the velocity: speed $= |\text{velocity}|$. There is also a similar distinction between *displacement* and *distance*. Displacement includes a direction while distance does not. A displacement can be positive or negative, while distance is always positive. For **uniform motion only**, the distance is the magnitude of the displacement: distance $= |\text{displacement}|$.

D: Velocity and Position-Time Graphs

Your last challenge is to find the velocity of a person from a position-time graph.

1. Explain how finding the velocity is different from simply finding the speed.

2. How can you determine the direction in which the person is moving? If you can, give two methods.

3. Determine the velocity of the person between:
   a) 0 and 6 seconds:
   
   b) 6 and 9 seconds:
   
   c) 9 and 15 seconds:
SPH3U: Velocity-Time Graphs

We have had a careful introduction to the idea of velocity. Now it’s time to look at its graphical representation.

A: The Velocity-Time Graph

A velocity-time graph uses a sign convention to indicate the direction of motion. We will make some predictions and investigate the results using the motion sensor. Remember that the positive direction is away from the face of the sensor.

1. Predict. (work individually) A student walks slowly away from the sensor with a constant velocity. Predict what the velocity-time graph will look like. You may assume that the student is already moving when the sensor starts collecting data.

2. Observe. (as a class) Observe a student and record the results from the computer. You may smooth out the jiggly data from the computer.

3. Explain. Most students predict a graph for the previous example that looks like the one to the right. Explain what the student was thinking when making this prediction.

4. Predict. (Work individually) Sketch your prediction for the velocity-time graph that corresponds to each situation described in the chart below. Use a dashed line for your predictions.

5. Discuss. (Work together) Compare your predictions with your group members and discuss any differences. Don’t worry about making changes.

6. Observe. (As a class) The computer will display its results for each situation. Draw the results with a solid line on the graphs above. Remember that we want to smooth out the bumps and jiggles from the data.

Adapted from Workshop Physics Activity Guide: I – Mechanics, Laws, John Wiley & Sons, 2004
7. **Explain.** Explain to your group members any important differences between your personal prediction and the results.

8. **Explain.** Based on your observations of the graphs above, how is speed represented on a velocity-time graph? (How can you tell if the object is moving fast or slow)?

9. **Explain.** Based on your observations of the graphs above, how is direction represented on a velocity-time graph? (How can you tell if the object is moving in the positive or negative direction)?

10. **Explain.** If everything else is the same, what effect does the starting position have on a v-t graph?

**B: Prediction Time!**

A person walks away from the sensor slowly and steadily for 6 seconds, stands still for 6 seconds, and walks towards the sensor steadily about twice as fast as before.

1. **Predict.** *(Work individually)* Use a dashed line to draw your prediction for the shape of the velocity-time graph for the motion described above.

2. **Discuss.** *(Work together)* Compare your predictions with your group and see if you can all agree.

3. **Observe.** *(As a class)* Compare the computer results with your group’s prediction. Explain to your group members any important differences between your personal prediction and the results. Record your explanations here.

Velocity is a vector quantity since it has a magnitude (number) and direction. All vectors can be represented as arrows. In the case of velocity, the arrow does not show the initial and final positions of the object. Instead it shows the object’s speed and direction. We can use a scale to draw a velocity vector, for example: 1.0 cm (length on paper) = 1.0 m/s (real-world speed).

4. **Represent.** Refer to the graph above. Draw two vector arrows to represent the velocity of our walker at 4 seconds and at 14 seconds. Label them \( v_1 \) and \( v_2 \). Use a scale of 10 cm = 1.0 m/s.
1. A motion diagram tracks the movement of a remote control car. The car is able to move back and forth along a straight track and produces one dot every second.

(a) Is the velocity of the car constant during the entire trip? Explain what happens and how you can tell.

(b) At what time does the motion change? Explain.

(c) Sketch a position-time graph for the car. The scale along the position axis is not important. Use one grid line = 1 second for the time axis. Explain how the slopes of the two sections compare.

(d) Sketch a velocity-time graph for the car. The scale along the velocity axis is not important. Use one grid line = 1 second for the time axis.

2. In a second experiment we track the same car and create a new motion diagram. We begin tracking at event one and finish at event 2.

(a) Is the velocity of the car constant during the entire trip? Explain what happens and how you can tell.

(b) Does the car spend more time traveling fast or slow? Explain how you can tell.

(c) Sketch a position-time graph for the car. The scale along the position axis is not important. Use one grid line = 1 second for the time axis. Explain how the slopes of the two sections compare.

(d) Sketch a velocity-time graph for the car. The scale along the velocity axis is not important. Use one grid line = 1 second for the time axis. Explain how you chose to draw each section of the velocity-time graph.

(e) According any velocity-time graph, how can you tell what direction an object is moving in?
In our daily life we often encounter different units that describe the same thing – speed is a good example of this. Imagine we measure a car’s speed and our radar gun says “100 km/h” or “62.5 miles per hour”. The numbers (100 compared with 62.5) might be different, but the measurements still describe the same amount of some quantity, which in this case, is speed.

A: Units and Conversions

When we say that something is 3 m long, what do we really mean?

1. Explain. “3 metres” or “3 m” is a shorthand way of describing a quantity using a mathematical calculation. You may not have thought about this before, but there is a mathematical operation (+, -, x, ÷) between the “3” and the “m”. Which one is it? Explain.

Physics uses a standard set of units, called S. I. units, which are not always the ones used in day-to-day life. The S. I. units for distance and time are metres (m) and seconds (s). It is an important skill to be able to change between commonly used units and S.I. units.

2. Reason. Albert measures a weight to be 0.454 kg. He does a conversion calculation and finds a result of 1.00 lbs. He places a 0.454 kg weight on one side of a balance scale and a 1.00 lb weight on the other side. What will happen to the balance when it is released? Explain what this tells us physically about the two quantities 0.454 kg and 1.00 lbs.

3. Reason. There is one number we can multiply a measurement by without changing the size of the physical quantity it represents. What is that number?

The process of conversion between two sets of units leaves the physical quantity unchanged – the number and unit parts of the measurement will both change, but the result is always the same physical quantity (the same amount of stuff), just described in a different way. To make sure we don’t change the actual physical quantity when converting, we only ever multiply the measurement by “1”. We multiply the quantity by a conversion ratio which must always equal “1”.

\[
0.454 \text{ kg} = 0.454 \left( \frac{2.203 \text{ lbs}}{1 \text{ kg}} \right) = 1.00 \text{ lbs}
\]

\[
65 \frac{\text{km}}{\text{h}} = 65 \left( \frac{\frac{1 \text{ km}}{3600 \text{ s}}}{\frac{1 \text{ h}}{}}, \frac{1 \text{ h}}{} \right) = 1.8 \times 10^{-2} \text{ km/s}
\]

The ratio in the brackets is the conversion ratio. Note that the numerator and denominator are equal, making the ratio equal to “1”. It is usually helpful to complete your conversions in the first step of your problem solving.

4. Explain. Examine the conversion ratios in the example above. When converting, you need to decide which quantity to put on the top and the bottom of the fraction. Explain how to decide this. A hint comes from the markings and units in the examples above.

5. Solve. Convert the following quantities. Carefully show your conversion ratios and how the units divide out. How many significant digits should your converted quantities have?

<table>
<thead>
<tr>
<th>Convert to seconds</th>
<th>Convert to metres</th>
<th>Convert to kilograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 hours =</td>
<td>4.5 km =</td>
<td>138 lbs =</td>
</tr>
</tbody>
</table>
**Check with your teacher before proceeding**

**B: Problem Solving**

We can build a deep understanding of physics by learning to think carefully about each problem we solve. Our goal will be to do a small number of problems really well and to learn as much as possible from each one. To help do this, we will use a special process shown below to carefully describe or represent a problem in many different ways. Read the example below.

**A: Pictorial Representation**

Sketch, coordinate system, label given information, conversions, key events, unknowns

**B: Physics Representation**

Motion diagram, motion graphs, force diagram, events

**C: Word Representation**

Describe / Explain the physics: why, how?

The runner passes the 60 m mark and travels with a constant velocity past the 80 m mark.

**D: Mathematical Representation**

Complete equations, describe steps, algebraic work, substitutions with units, final statement

Solve for time:

\[ v = \frac{\Delta x}{\Delta t} \]

\[ \therefore \Delta t = \frac{\Delta x}{v} \]

Find the displacement:

\[ \Delta x = x_2 - x_1 = 80 \text{ m} - 60 \text{ m} = 20 \text{ m} \]

Calculate the time:

\[ \Delta t = \frac{\Delta x}{v} = \frac{20 \text{ m}}{10.7 \text{ m/s}} = 1.86 \text{ s} \]

The runner took 1.9 s to run the distance.

**E: Evaluation**

Answer has reasonable size, direction and units?

A small time interval is reasonable since she is running quickly and travels through a short distance. Time does not have a direction. The units are seconds which are reasonable for a short time interval.
1. **Describe.** Pretend you are a physics textbook author. Write the original question for the problem presented above. Be creative!

2. **Solve.** Use the new process to solve the following problems. You may write them up on a blank sheet of paper so long as you clearly show the five headings. Or, use the blank solution sheet that your teacher may provide.

**Problems**

1. Usain Bolt ran the 200 m sprint at the 2012 Olympics in London in 19.32 s. Assuming he was moving with a constant velocity, what is his speed in km/h during the race?

2. Nolan Ryan once threw a 100.9 mph fastball. How much time did the ball take to reach home plate 18.4 m away?

3. NASA’s Upper Atmosphere Research Satellite (UARS) fell to Earth back in 2011. NASA stated that it is difficult to predict the satellite’s exact path, but they would be able to give a two hour warning before it finally fell. The 6-tonne satellite was traveling at a steady speed of 7.0 km/s. How many kilometers can it travel in 2.0 hours? (Interesting fact: Canada is over 4000 km across.)

4. If the Sun suddenly dies out, the last ray of light would travel $1.5 \times 10^{11}$ m to Earth with a speed of $3.0 \times 10^8$ m/s. How many minutes would elapse between the Sun dying and the inhabitants of Earth seeing things go dark?
Homework: Physics and Numbers

Physics can be written in the language of mathematics, so we need to be comfortable with our mathematical skills.

A: Algebra
An important skill in physics is being able to isolate a variable in one of our common equations. This should always be done before you substitute any numbers into the equation to find an answer. A good example of this can be found in this video: http://youtu.be/lQ-dvt3V4yQ. The examples below present typical physics equations (and one you haven’t met yet!)

1. **Velocity:** \( v = \frac{\Delta x}{\Delta t} \)
   - Solve for displacement:
   - Explain the algebraic steps:
   - Describe how displacement depends on the time:

2. **Acceleration:** \( a = \frac{\Delta v}{\Delta t} \)
   - Solve for the time:
   - Explain the algebraic steps:
   - Describe how the time to change velocity (i.e. speed up) depends on the size of the acceleration:

3. **Velocity:** \( v = \frac{(x_2 - x_1)}{\Delta t} \)
   - Solve for \( x_2 \):
   - Explain the algebraic steps:
   - Describe how the final position \( (x_2) \) depends on the time during which an object is moving:

B: Scientific Notation
Numbers that are either very large or very small are more convenient to write using scientific notation. This notation is also useful for explicitly showing significant figures. Try few sample exercises to refresh your skills with these numbers.

1. Rewrite each measurement using scientific notation. Remember – only the significant figures are used!
   - (a) 3 230 kg
   - (b) 1 400 000 m
   - (c) 0.0049 s
   - (d) 14.79 km/h
   - (e) 57 000 km
   - (f) 0.580 m/s
2. Rewrite each measurement using traditional decimal notation.
   - (a) 5.7 x 10^3 m
   - (b) 1.703 x 10^6 s
   - (c) 2.998 x 10^8 m/s
   - (d) 3.2 x 10^{-3} m
   - (e) 1.02 x 10^{-2} kg
   - (f) 6.9 x 10^0 km/h

**General Guideline for Significant Figures:** When performing calculations, write the intermediate results with one extra significant figure and the final answer with no more significant figures than the piece of data with the least. This is a handy but very approximate rule of thumb. In university you will learn a mathematical system for determining the error in your calculated results which will replace this handy rule.

C: Calculation Skills
Make sure you can correctly use your calculator! Scientific notation is entered using buttons that look like the examples to the right. Try performing the following calculation yourself! Don’t forget to use the guideline for significant figures.

\[ x_1 = 1.37 \times 10^5 \text{ m}, x_2 = 5.982 \times 10^5 \text{ m}, \Delta t = 8.3 \times 10^3 \text{ s} \] – Find \( v \)
Homework: Representations of Motion

Each column in the chart below shows five representations of one motion. The small numbers represent the events. Remember that the motion diagram is a dot pattern. If the object remains at rest, simply “pile up” the dots. If it changes direction, use a separate line just above or below the first. See the example on the next page. Remember that in the motion diagrams the origin is marked by a small vertical line. There is at least one completed example of each type of representation that you can use as a guide – check the next page as well!

<table>
<thead>
<tr>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
<th>Situation 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Description</td>
<td>Description</td>
<td>Description</td>
</tr>
</tbody>
</table>

Position Graph

```
| 1 | 2 | 3 | 4 |
```

Velocity Graph

```
| 1 | 2 | 3 | 4 |
```

Motion Diagram


Velocity Vectors

\[ \text{velocity just after each event} \]

\[ v_1 \]
\[ v_2 \]
\[ v_3 \]
<table>
<thead>
<tr>
<th>Situation 5</th>
<th>Situation 6</th>
<th>Situation 7</th>
<th>Situation 8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td><strong>Description</strong></td>
<td><strong>Description</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>The object starts +5 m from the origin. The object moves with a constant positive velocity for four seconds. Then it stops for 2 seconds. Then it moves with a constant negative velocity until it reaches its initial position.</td>
<td>Object A starts 10 m to the right or the origin and moves to the left at 2 m/s. Object B starts at the origin and moves to the right at 3 m/s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Position Graph**

**Velocity Graph**

**Motion Diagram**

**Velocity Vectors**

$v_1$
$v_2$
$v_3$
SPH3U: Changing Velocity

We have explored the idea of velocity and now we are ready to test it carefully and see how far this idea goes. One student, Isaac, proposes the statement:

“the quantity \( \Delta x/\Delta t \) gives us the velocity of an object at each moment in time during the time interval \( \Delta t \)”. 

A: The Three-Section Track

Your teacher has set up a track with three sections. Two sections are horizontal and one is at an angle. After you start it, an object rolls from point A to point D along the track without any friction or other pushing. The length of each track and the time the ball takes to roll across that section of track is indicated.

Record your answers to the following questions in the chart below.

1. **Observe.** Describe how the object moves while travelling along each section of the track.
2. **Calculate.** Calculate the quantity \( \Delta x/\Delta t \) for each section.
3. **Reason.** Does Isaac’s statement hold true (is it valid) for each section of the track? Explain why or why not.

<table>
<thead>
<tr>
<th></th>
<th>Section AB</th>
<th>Section BC</th>
<th>Section CD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>( \Delta t = 1.50 \text{ s}, \Delta x = 2.0 \text{ m} )</td>
<td>( \Delta t = 1.00 \text{ s}, \Delta x = 2.0 \text{ m} )</td>
<td>( \Delta t = 0.75 \text{ s}, \Delta x = 2.0 \text{ m} )</td>
</tr>
<tr>
<td>( \Delta x/\Delta t )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Valid?</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **Conclusion.** For what types of motion is Isaac’s statement valid and invalid?

We can conclude that our simple expression \( \Delta x/\Delta t \) does not reliably give us the velocity of an object at each moment in time during a large time interval. The quantity \( \Delta x/\Delta t \) represents the *average velocity* of an object during an interval of time. Only if the velocity of an object is constant will it also give us the velocity at each moment in time. If the velocity is not constant, we need another way of finding the velocity at one moment in time. This is a very tricky problem! Let’s start by exploring the motion of an object with a changing velocity.

B: Motion with Changing Velocity

Your teacher has a tickertape timer, a cart and an incline set-up. Turn on the timer and then release the cart to run down the incline. Bring the tickertape back to your table to analyze.

1. **Observe.** Examine the pattern of dots on your tickertape. How can you tell whether or not the velocity of the cart was constant?

2. **Find a Pattern.** Divide the tape into intervals of six *spaces* as shown below.

Adapted from *Physics by Inquiry*, McDermott and PEG U. Wash, © John Wiley and Sons, 1996
3. **Reason.** The timer is constructed so that it hits the tape 60 times every second. What is the duration of each six-space interval; that is, how much time does each six space-interval take? Explain your reasoning.

4. **Calculate and Interpret.** Divide the total displacement by the total duration of the trip. Can this number be interpreted as the number of centimetres travelled by the cart each second? Explain.

5. **Observe.** Find the first 1.0 s of the cart’s motion on the ticker tape. Mark the midpoint in time (0.5 s) on the ticker tape. Describe how the displacements during the first 0.5 seconds and the last 0.5 seconds of the interval compare. Record the displacements in the table below.

6. **Observe.** Now focus your attention on the 0.1-second intervals just before and after the 0.5 s point. How do these two small displacements compare? Record your measurements in the table below.

7. **Observe.** Finally, examine the 1/60 s intervals just before and after the 0.5 s point. How do these two tiny displacements compare? Record your measurements in the table below.

<table>
<thead>
<tr>
<th>Total Interval</th>
<th>Displacement in first half</th>
<th>Displacement in second half</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 s</td>
<td>( \Delta d (0 - 0.5 \text{ s}) = )</td>
<td>( \Delta d (0.5 - 1.0 \text{ s}) = )</td>
</tr>
<tr>
<td>0.2 s</td>
<td>( \Delta d (0.4 - 0.5 \text{ s}) = )</td>
<td>( \Delta d (0.5 - 0.6 \text{ s}) = )</td>
</tr>
<tr>
<td>2/60 s</td>
<td>( \Delta d (0.48 - 0.5 \text{ s}) = )</td>
<td>( \Delta d (0.5 - 0.52 \text{ s}) = )</td>
</tr>
</tbody>
</table>

8. **Conclusion.** How does the appearance of an object’s velocity change as we examine smaller and smaller time intervals? Explain.

The velocity looks more and more …

We now introduce a new concept: instantaneous velocity. If we want to know the velocity of an object at a particular moment in time, what we need to do is look at a very small interval which contains that moment. It is convenient for the moment be at the middle of the small interval. We must first make sure the interval is small enough that the velocity is very nearly uniform. We then measure \( \Delta x \), measure \( \Delta t \), and divide. The number obtained this way is very close to the instantaneous velocity at that moment (instant) in time. This quantity could be represented by the symbol \( v_{\text{inst}} \) but is more commonly written as just \( v_1 \) or \( v_2 \) (the instantaneous velocity of the object at event 1 or 2). The magnitude of the instantaneous velocity is the instantaneous speed. From now on, the terms velocity and speed will always be understood to mean instantaneous velocity and instantaneous speed, respectively.

Suppose the instantaneous velocity of an object is -45 cm/s in a small interval. We interpret this to mean that the object would travel 45 cm in the negative direction *if* it continued to move at the same velocity (without speeding up or slowing down) and *if* the motion continued that way for an entire second.
When the interval chosen is not small enough and the velocity is measurably not constant, the ratio \( \Delta x / \Delta t \) gives the \textit{average velocity} during that interval which is represented by the symbol \( v_{avg} \).

9. **Apply.** Calculate \( \Delta x / \Delta t \) for the 2/60 s interval. Interpret this result according to the explanation above.

### C: Analyzing Changing Velocity

1. **Observe.** Collect a complete set of position and time data from your tickertape. Begin by marking on your tape the origin that you will use for every position measurement. Use 0.1-second intervals and measure the position the cart from the origin to the end of the interval you are considering. Record the data the chart below.

2. **Represent.** Plot the data in a graph of position vs. time. Does a straight line or a smooth curve fit the data best? Explain.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Position (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

3. **Explain.** Albert says, “I don’t understand why the position graph should be curved in this situation.” Explain to Albert why it must be curved in the case of changing velocity.

4. **Explain.** What can we say about how the steepness of the curve changes. Remind yourself – what does the steepness (slope) of a position-time graph represent?
When a graph is curved, it rises by a different amount for each unit of run. To find out how much the graph is rising per unit of run at a particular point (instant), we must look at a small interval that contains the point. If the interval is small enough, the graph behaves much like a straight-line graph. We can then find the slope just as with a straight-line graph: the rise divided by the run.

We interpret the slope as the *rise per unit run* the graph *would* have if the graph did not curve anymore, but continued as a straight line. This imaginary straight line is called the *tangent to the graph* at the point of interest. We then extend this straight line in both directions to form the tangent.

**The slope of a position-time graph at an instant gives the instantaneous velocity at that instant.**

Consider the graph shown to the right. Always calculate the slope of a curved graph by drawing the tangent, extending it a great distance on both sides of the point of interest, and choosing two points on the tangent that are far apart.

1. **Calculate.** Find the slope of the tangent that is already drawn for you.

2. **Interpret.** How do we interpret the result for the slope you just found?

   The slope represents the ...

3. **Calculate.** Draw a new tangent to the graph at 0.3 s. Determine the instantaneous velocity at 0.3 seconds.

4. **Analyze.** Return to your table of data in Part C of this investigation. Title the third column “Velocity (cm/s)”. Use your data table to determine the instantaneous velocity of the cart at 0.2 s, 0.5 s and 0.8 s. Explain below what size of an interval of time you chose in order to calculate an instantaneous velocity.

5. **Explain.** Albert makes a calculation for the previous question: \(\Delta x/\Delta t = 43 \text{ cm} / 0.5 \text{ s} = 86 \text{ cm/s}\). Emmy says, “I don’t think you can find the instantaneous velocity at 0.5 s by using a time interval and displacement from 0 to 0.5 s.” Do you agree or disagree with Emmy? What quantity did Albert actually calculate?

6. **Calculate.** Draw a tangent to the graph of your data at 0.5 s and use its slope to determine the instantaneous velocity. How does this compare with the value you calculated from the table?
SPH3U: The Idea of Acceleration

A: The Idea of Acceleration
Interpretations are powerful tools for making calculations. Please answer the following questions by thinking and explaining your reasoning to your group, rather than by plugging into equations. Consider the situation described below:

* A car was traveling with a constant velocity 20 km/h. The driver presses the gas pedal and the car begins to speed up at a steady rate. The driver notices that it takes 3 seconds to speed up from 20 km/h to 50 km/h.

1. **Reason.** How fast is the car going 2 seconds after starting to speed up? Explain.

2. **Reason.** How much time does it take to go from 20 km/h to 75 km/h? Explain.

3. **Interpret.** A student who is studying this motion subtracts 50 – 20, obtaining 30. How would you interpret the number 30? What are its units?

4. **Interpret.** Next, the student divides 30 by 3 to get 10. How would you interpret the number 10? (Warning: don’t use the word acceleration, instead explain what the 10 describes a change in. What are the units?)

B: Watch Your Speed!
Shown below are a series of images of a speedometer in a car showing speeds in km/h. Along with each is a clock showing the time (hh:mm:ss). Use these to answer the questions regarding the car’s motion.

1. **Reason.** What type of velocity (or speed) is shown on a speedometer – average or instantaneous? Explain.

2. **Explain.** Is the car speeding up or slowing down? Is the change in speed steady?
3. **Explain and Calculate.** Explain how you could find the acceleration of the car. Calculate this value and write the units as \((\text{km/h})/\text{s}\).

4. **Interpret.** Marie exclaims, “In our previous result, why are there two different time units: hours and seconds? This is strange!” Explain to the student the significance of the hours unit and the seconds unit. The brackets provide a hint.

**C: Interpreting Motion Graphs**

To the right is the velocity versus time graph for a particular object. Two events, 1 and 2, are indicated on the graph.

1. **Interpret.** Based on the graph, what do we know about the object when events 1 and 2 occur? We will label the velocity at event 1 \(v_1\) and at event 2 \(v_2\).

2. **Interpret.** Give an interpretation of the interval labelled \(c\). What symbol should be used to represent this?

3. **Interpret.** Give an interpretation of the interval labelled \(d\). What symbol should be used to represent this?

4. **Interpret.** Give an interpretation of the ratio \(d/c\). How is this related to our discussion in part A?

5. **Calculate.** Calculate the ratio \(d/c\) including units. Write the units in a similar way to question B#3.

6. **Reason.** Use your grade 8 knowledge of fractions to show how to simplify the units of \((\text{m/s})/\text{s} = \frac{m}{s} \div s\)
A: Defining Acceleration

The number calculated for the slope of the graph in part C of last class’s investigation is called the acceleration. The motions shown in parts A, B and C of that investigation all have the characteristic that the velocity of the object changed by the same amount in equal time intervals. When an object’s motion has this characteristic, we say that the object has constant acceleration. In this case, the total change in velocity is shared equally by all equal time intervals. We can therefore interpret the number Δv/Δt as the change in velocity occurring in each unit of time. The number, Δv/Δt, is called the acceleration and is represented by the symbol, a.

\[ a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}, \] if the acceleration is constant

In Gr. 11 physics, we will focus on situations in which the acceleration is constant (sometimes called uniform acceleration). Acceleration can mean speeding up, slowing down, or a change in an object’s direction - any change in the velocity qualifies!

Note in the equation above, we wrote \( v_f \) and \( v_i \) for the final and initial velocities during some interval of time. If your time interval is defined by events 2 and 3, you would write \( v_3 \) and \( v_2 \) for your final and initial velocities.

1. We mentioned earlier that the “Δ” symbol is a short form. In this case, explain carefully what Δv represents using both words and symbols.

B: A Few Problems!

1. A car is speeding up with constant acceleration. You have a radar gun and stopwatch. At a time of 10 s the car has a velocity of 4.6 m/s. At a time of 90 s the velocity is 8.2 m/s. What is the car’s acceleration?
In the previous example, if you did your work carefully you should have found units of m/s² for the acceleration. It is important to understand that the two seconds in m/s² (m/s² is shorthand) play different roles. The second in m/s is just part of the unit for velocity (like hour in km/h). The other second is the unit of time we use when telling how much the velocity changes in one unit of time.

2. **Hit the Gas!** You are driving along the 401 and want to pass a large truck. You floor the gas pedal and begin to speed up. Your start at 102 km/h, accelerate at a steady rate of 4.3 (km/h)/s (obviously not a sports car). What is your velocity after 6.5 seconds when you finally pass the truck?

   **A: Pictorial Representation**
   Sketch, coordinate system, label given information, conversions, key events, unknowns

   **B: Physics Representation**
   Motion diagram, motion graphs, events

   **C: Word Representation**
   Describe / Explain the physics: why, how?

   **D: Mathematical Representation**
   Complete equations, describe steps, algebraic work, substitutions with units, final statement

   **E: Evaluation**
   Answer has reasonable size, direction and units?

3. **The Rattlesnake Strike** The head of a rattlesnake can accelerate at 50 m/s² when striking a victim. How much time does it take for the snake’s head to reach a velocity of 50 km/h?

   **A: Pictorial Representation**
   Sketch, coordinate system, label given information, conversions, key events, unknowns

   **B: Physics Representation**
   Motion diagram, motion graphs, events

   **C: Word Representation**
   Describe / Explain the physics: why, how?
4. **The Rocket** A rocket is travelling upwards. The engine fires harder causing it to speed up at a rate of 21 m/s². After 7.3 seconds it reached a velocity of 413 km/h and the engine turns off. What was the velocity of the rocket when the engines began to fire harder?

**A: Pictorial Representation**
- Sketch, coordinate system, label given information, conversions, key events, unknowns

**B: Physics Representation**
- Motion diagram, motion graphs, events

**C: Word Representation**
- Describe / Explain the physics: why, how?

**D: Mathematical Representation**
- Complete equations, describe steps, algebraic work, substitutions with units, final statement

**E: Evaluation**
- Answer has reasonable size, direction and units?
1. Answer the following questions based on the graph. Provide a brief explanation how you could tell.

   a) At what times, if any does the object have a positive acceleration and a negative velocity?

   b) At what times, if any does the object have a negative acceleration and a positive velocity?

   c) At what times, if any, was the acceleration zero?

   d) At what times, if any, was the object speeding up?

   e) At what times, if any, was the object slowing down?

   f) At what times, if any, did the object sit still for an extended period of time?

   g) Overall, is the motion in the graph an example of uniform or nonuniform acceleration?

2. Answer the following questions based on the graph. Provide a brief explanation how you could tell. At which of the lettered points on the graph below:

   a) is the motion slowest?

   b) is the object speeding up?

   c) is the object slowing down?

   d) is the object turning around?

3. A car’s velocity changes from +40 km/h to +30 km/h in 3 seconds. Is the acceleration positive or negative? Find the acceleration.
There is one mystery concerning acceleration remaining to be solved. Our definition of acceleration, $\frac{\Delta v}{\Delta t}$, allows the result to be either positive or negative, but what does that mean? Today we will get to the bottom of this.

**A: Acceleration in Graphs**

Your teacher has set-up a cart with a fan on a dynamics track and a motion detector to help create position-time and velocity-time graphs. Let’s begin with a position graph before we observe the motion. The cart is initially moving forward. The fan is on and gives the cart a steady, gentle push which causes the cart to accelerate.

1. **Interpret.** What does the slope of a tangent to a position-time graph represent?

2. **Reason.** Is the cart speeding up or slowing down? Use the two tangents to the graph to help explain.

3. **Reason.** Is the change in velocity positive or negative? What does this tell us about the acceleration?

4. **Predict.** What will the velocity-time graph look like? Sketch this graph on the axes above.

5. **Test. (as a class)** Observe the velocity-time graph produced by the computer for this situation. Explain any differences between your prediction and your observations.

**B: The Sign of the Acceleration**

All the questions here refer to the chart on the next page.

1. **Represent.** In the chart, draw an arrow corresponding to the direction the fan pushes on the cart. Label this arrow “F” for the force.

2. **Predict. (work individually)** For each situation (each column), use a dashed line to sketch your prediction for the position- and velocity-time graphs that will be produced. Complete the graphs for each example on our own and then compare your predictions with your group. Note: It may be easiest to start with the $v$-$t$ graph and the acceleration-time graph is new!

3. **Test. (as a class)** Observe the results from the computer. Use a solid line to draw the results for the three graphs in the chart on the next page.

4. **Interpret.** Examine the velocity graphs. Is the magnitude of the velocity (the speed) getting larger or smaller? Decide whether the cart speeding up or slowing down.

5. **Interpret.** Use the graphs to decide on the sign of the velocity and the acceleration.
<table>
<thead>
<tr>
<th>Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>The cart is released from rest near the motion detector. The fan pushes away from the detector.</td>
<td>The cart is released from rest far from the detector. The fan pushes towards the detector.</td>
<td>The cart is moving away from the detector. The fan pushes towards the detector.</td>
<td>The cart is moving towards the detector. The fan is pushing away from the detector.</td>
<td></td>
</tr>
<tr>
<td>Sketch with Force</td>
<td><img src="image1" alt="Sketch with Force" /></td>
<td><img src="image2" alt="Sketch with Force" /></td>
<td><img src="image3" alt="Sketch with Force" /></td>
<td><img src="image4" alt="Sketch with Force" /></td>
</tr>
<tr>
<td>Position graph</td>
<td><img src="image5" alt="Position graph" /></td>
<td><img src="image6" alt="Position graph" /></td>
<td><img src="image7" alt="Position graph" /></td>
<td><img src="image8" alt="Position graph" /></td>
</tr>
<tr>
<td>Velocity graph</td>
<td><img src="image9" alt="Velocity graph" /></td>
<td><img src="image10" alt="Velocity graph" /></td>
<td><img src="image11" alt="Velocity graph" /></td>
<td><img src="image12" alt="Velocity graph" /></td>
</tr>
<tr>
<td>Acceleration graph</td>
<td><img src="image13" alt="Acceleration graph" /></td>
<td><img src="image14" alt="Acceleration graph" /></td>
<td><img src="image15" alt="Acceleration graph" /></td>
<td><img src="image16" alt="Acceleration graph" /></td>
</tr>
<tr>
<td>Slowing down or speeding up?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sign of Velocity</td>
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<tr>
<td>Sign of Acceleration</td>
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</tbody>
</table>

Now let’s try to interpret the sign of the acceleration carefully. Acceleration is a vector quantity, so the sign indicates a direction. This is not the direction of the object’s motion! To understand what it is the direction of, we must do some careful thinking.

6. **Reason.** Albert says, “We can see from these results that when the acceleration is positive, the object always speeds up.” Do you agree with Albert? Explain.

7. **Reason.** What conditions for the acceleration and velocity must be true for an object to be speeding up? To be slowing down?

8. **Reason.** Which quantity in our chart above does the sign of the acceleration always match?

Always compare the magnitudes of the velocities, the speeds, using the terms faster or slower. Describe the motion of accelerating objects as **speeding up** or **slowing down** and state whether it is moving in the positive or negative direction. Other ways of describing velocity often lead to ambiguity and trouble! **Never** use the d-word, deceleration - yikes! Note that we will always assume the acceleration is uniform (constant) unless there is a good reason to believe otherwise.
SPH3U: Area and Averages

A graph is more than just a line or a curve. We will discover a very handy new property of graphs which has been right under our noses (and graphs) all this time!

A: Looking Under the Graph

A car drives along a straight road at 20 m/s. It is straightforward to find the displacement of the car between 5 to 20 seconds. But instead, let’s look at the velocity-time graphs and find another way to represent this displacement.

1. **Describe.** How do we calculate the displacement of the car the familiar way?

2. **Sketch.** Now we will think about this calculation in a new way. Draw and shade a rectangle on the graph that fills in the area between the line of the graph and the time axis, for the time interval of 5 to 20 seconds.

3. **Describe.** In math class, how would you calculate the area of the rectangle?

4. **Interpret.** Calculate the area of the rectangle. Note that the length and width have a meaning in physics, so the final result is not a physical area. Use the proper physics units that correspond to the height and the width of the rectangle. What physics quantity does the final result represent?

The area under a velocity-time graph for an interval of motion gives the displacement during that interval. Both velocity and displacement are vector quantities and can be positive or negative depending on their directions. According to our usual sign convention, areas above the time axis are positive and areas below the time axis are negative.

B: Kinky Graphs

Here’s a funny-looking graph. It has a kink or corner in it. What’s happening here?

1. **Interpret.** What characteristic of the graph is steady before the kink, steady after the kink, but changes right at the kink? What has happened to the motion of the object?

   At $t = 0.75$ seconds we cannot tell what the slope is – it is experiencing an abrupt change.
2. **Represent.** Sketch a velocity-time graph for the motion in the graph above.

To indicate a sudden change on a physics graph, use a dashed vertical line. This indicates that you understand there is a sudden change, but you also understand that you cannot have a truly vertical line.

3. **Reason.** What would a vertical line segment on a v-t graph mean? Is this physically reasonable? Explain.

4. **Calculate.** Find the area under the v-t graph you have just drawn for the time interval of 0 to 1.0 seconds. Find this result. Explain how to use the original position-time graph to confirm your result.

5. **Calculate.** We can perform a new type of calculation by dividing the area we found by the time interval. Carry out this calculation and carefully show the units.

6. **Interpret.** What type of velocity did you find from the previous calculation? How does it compare with the values in the v-t graph? Overall (during the entire time interval), is motion of the object uniform or nonuniform?

**C: Average Velocity**

Earlier in this unit, we noted that the ratio, \( \frac{\Delta x}{\Delta t} \), has no simple interpretation if the motion of the object is nonuniform. Since the velocity is changing during the time interval, this ratio gives an **average velocity** for that time interval. One way to think about it is this: \( \frac{\Delta x}{\Delta t} \) is the velocity the object *would have if* it moved with uniform motion through the same displacement in the same amount of time.

1. **Represent.** Use the interpretation above to help you draw a single line (uniform motion) on the d-t graph above and show that its slope equals the average velocity for that time interval. Show your work on the graph.

Adapted from *Physics by Inquiry*, McDermott and PEG U. Wash, © John Wiley and Sons, 1996
Now we come to a real challenge for this unit. A car is travelling at 60 km/h along a road when the driver notices a student step out in front of the car, 34 m ahead. He slams on the brakes of the car which slows the car at a rate of 7.7 m/s². Does the car hit the student? Let’s begin with a video!

A: Modelling Displacement for Uniform Acceleration
1. **Reason.** In the video, two separate distances make up the stopping distance: the reaction distance and the braking distance. Describe why there are two intervals and how the car moves during each.

To model the car, we make two important assumptions: First, the object in question will be modelled as a point particle – essentially a tiny blob with the same mass as the actual vehicle. Second, the acceleration experienced by the car will be uniform. If either of these assumptions is not realistic enough, our calculations won’t give reliable results.

Our goal is to find a displacement value for the situation of uniform acceleration. One major problem is that we have no equations that relate $\Delta x$ to changing velocities. Luckily for us, we do know how to relate these quantities using graphs, and from that we can create new equations! Fasten your seatbelts!

B: Relating Graphs to Equations
Consider the following graph which shows an example (different from the car example above) of uniformly accelerated motion. We will use it to find the displacement between the times $t_i$ and $t_f$. This looks tricky, but notice that the area can be split up into two simpler shapes.

1. **Represent.** What is the height and the width of the rectangle? Use these to write an expression for its area using kinematic symbols.

2. **Represent.** What is the height and width of the triangle? Write an expression for its area.

3. **Represent.** Remember our equation: $a = \Delta v/\Delta t$? If we rearrange it, we have: $\Delta v = a\Delta t$. Use this expression for $\Delta v$ to write down a new expression for the area of the triangle that does not use $\Delta v$.

4. **Represent.** The total area represents the displacement of the object during the time interval. Write a complete expression for the displacement.
The equation you have just constructed is one of the five equations of uniform acceleration (affectionately known as the BIG five). Together they help relate different combinations of the five kinematic variables: \( \Delta x, a, v_i, v_f \) and \( \Delta t \). You have encountered one other BIG five so far, (in a disguised form) the definition of acceleration: \( a = \frac{\Delta v}{\Delta t} \). Recall that this equation was also constructed by analyzing a graph! With a bit more algebraic work, which we won’t ask you to do here, you can use these two equations to create another one: \( v_f^2 = v_i^2 + 2a\Delta x \). This is the equation we will use as part of the solution to our problem.

C: Our Solution
It’s time to solve our car braking problem. People are often distracted while driving and are certainly not ready for the sudden appearance of a person on the road. We estimate the reaction time of the driver (the time from seeing the person to hitting the brake) to be 1.4 seconds.

In your problem solving, make sure you label the quantities using the event numbers. For example, the velocity at event 2 is \( v_2 \). When a problem has more than two events, label the intervals carefully. The time interval between events 2 and 3 is \( \Delta t_{23} \). The displacement between events 1 and 2 is \( \Delta x_{12} \). The acceleration between events 2 and 3 is \( a_{23} \). If there is only one time interval or displacement, you can just write \( \Delta t \) or \( \Delta x \) for convenience.

1. **Reason.** Which kinematic quantities would we like to find in order to solve this problem?

2. **Solve.** Work through the problem solving process for this problem. Make sure you label the three events!

   **A: Pictorial Representation**
   Sketch, coordinate system, label given information, conversions, key events, unknowns

   **B: Physics Representation**
   Motion diagram, motion graphs, key events

   **C: Word Representation**
   Explanation of physics: why, how? Assumptions

   **D: Mathematical Representation**
   Complete equations, describe steps, algebraic work, substitutions with units, final statement

   There are two important calculations: one for the interval of constant velocity and one for the slowing down interval \( (v_f^2 = v_i^2 + 2a\Delta x) \).
**E: Evaluation**

Answer has reasonable size, direction and units?

How does the size of your final result compare with other quantities in the video? Does it seem like it’s in the right range?

---

**Displacement Problem Homework**

1. **How fast was the car moving when it struck the student?** (Hint: Use the same equation as in D#4 but remember that we know how far the car is from the student when the car begins to brake.)

2. **Stopping a Muon** A muon (a subatomic particle) moving in a straight line enters a region with a speed of $5.00 \times 10^6$ m/s and then is slowed down at the rate of $1.25 \times 10^{14}$ m/s$^2$. How far does the muon take to stop? (Don’t forget to use GRASP and include a motion diagram with all your solutions!)

3. **Taking Off** A jumbo jet must reach a speed of 360 km/h on the runway for takeoff. What is the smallest constant acceleration needed to takeoff from a 1.80 km runway? Give your answer in m/s$^2$.

4. **Shuffleboard Disk** A shuffleboard disk is accelerated at a constant rate from rest to a speed of 6.0 m/s over a 1.8 m distance by a player using a cue. At this point the disk loses contact with the cue and slows at a constant rate of 2.5 m/s$^2$ until it stops. What total distance does the disk travel?

---

**Answers:** 1. 10.7 m/s; 2. 0.10 m; 3. 2.78 m/s$^2$; 4. 17.2 m
SPH3U: The BIG Five

Last class we found three equations to help describe uniformly accelerated motion. A bit more work along those lines would allow us to find two more giving us a complete set of equations for the five kinematic quantities.

A: The BIG Five – Revealed!

Here are the BIG five equations for uniformly accelerated motion. As part of your homework tonight memorize these!

<table>
<thead>
<tr>
<th>The BIG Five</th>
<th>$v_i$</th>
<th>$v_f$</th>
<th>$\Delta x$</th>
<th>$a$</th>
<th>$\Delta t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_f = v_i + a\Delta t$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta x = v_i\Delta t - \frac{1}{2}a\Delta t^2$</td>
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<td></td>
</tr>
<tr>
<td>$\Delta x = \frac{1}{2}(v_i + v_f)\Delta t$</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$(v_f)^2 = (v_i)^2 + 2a\Delta x$</td>
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</tbody>
</table>

1. **Observe.** Fill in the chart with √ and ✗ indicating whether or not a kinematic quantity is found in that equation.

2. **Find a Pattern.** How many quantities are related in each equation?

3. **Reason.** If you wanted to use the first equation to calculate the acceleration, how many other quantities would you need to know?

4. **Describe.** Define carefully each of the kinematic quantities in the chart below.

<table>
<thead>
<tr>
<th>$v_i$</th>
<th>$v_f$</th>
<th>$\Delta x$</th>
<th>$a$</th>
<th>$\Delta t$</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

5. **Reason.** What condition must hold true (we mentioned these in the previous investigation) for these equations to give reasonable or realistic results?

B: As Easy as 3-4-5

Solving a problem involving uniformly accelerated motion is as easy as 3-4-5. As soon as you know three quantities, you can always find a fourth using a BIG five! Write your solutions carefully using our solution process. Use the chart to help you choose a BIG five. Here are some sample problems that we will use the BIG five to help solve. Note that we are focusing on certain steps in our work here – in your homework, make sure you complete all the steps!

**Problem 1**

A traffic light turns green and an anxious student floors the gas pedal, causing the car to acceleration at 3.4 m/s² for a total of 10.0 seconds. We wonder: How far did the car travel in that time and what’s the big rush anyways?
Problem 2
An automobile safety laboratory performs crash tests of vehicles to ensure their safety in high-speed collisions. The engineers set up a head-on crash test for a Smart Car which collides with a solid barrier. The engineers know the car initially travels at 100 km/h and the car crumples 0.78 m during the collision. The engineers have a couple of questions: How much time does the collision take? What was the car’s acceleration during the collision?

A: Pictorial Representation
Sketch, coordinate system, label given information, conversions, key events, unknowns

B: Physics Representation
Motion diagram, motion graphs, key events
Problem 3

Speed Trap The brakes on your car are capable of slowing down your car at a rate of 5.2 m/s². You are travelling at 137 km/h when you see a cop with a radar gun pointing right at you! What is the minimum time in which you can get your car under the 100 km/h speed limit?

A: Pictorial Representation
Sketch, coordinate system, label given information, conversions, key events, unknowns

B: Physics Representation
Motion diagram, motion graphs, key events

D: Mathematical Representation
Complete equations, describe steps, algebraic work, substitutions with units, final statement
SPH3U: Freefall

One of the most important examples of motion is that of falling objects. When an object is tossed or dropped we say that it is in freefall. How does an object move when it experiences freefall? Let’s find out!

A: Predicting Falling Motions

1. **Predict.** Describe how a ball would fall in as much detail as possible. Be sure to describe if the motion changes part way through. Explain the reasons for your predictions.

2. **Predict.** Describe how a coffee filter would fall in as much detail as possible. Be sure to describe if the motion changes part way through. Do you think the filter will fall more slowly or more rapidly than the ball? Explain the reasons for your predictions.

3. **Predict.** Describe how the coffee filter would fall if it is crumpled into a little ball. Be sure to describe if the motion changes part way through. Do you think the crumpled filter will fall more slowly or more rapidly than the rubber ball? Explain the reasons for your predictions.

4. **Test.** Describe your observations. Get a ball and coffee filter, drop them and see what happens. Be sure to try the ball and crumpled filter at the same time. How did they compare with your predictions? Offer a new explanation if your observations differed from your predictions.

B: Describing How Objects Rise and Fall

1. **Observe.** Toss the ball straight up a couple of times and then describe how you think it might be moving while it is travelling upwards. Is it: rising at a constant velocity, rising and accelerating, or changing part way through. What do you think and why?

2. **Observe.** Describe how you think the ball might be moving when it is travelling downwards. Is it: falling at a constant velocity, falling and accelerating, or changing part way through. What do you think and why?

3. **Speculate.** Do you think the acceleration when the ball is rising is different in some way than the acceleration when the ball is falling? Why or why not?

4. **Speculate.** What do you think the acceleration will be at the moment when the ball is at its highest point? Why?

---

**C: Analyzing the Motion of a Tossed Ball**

As a class, observe the motion of the tossed ball using the motion detector attached to the ceiling.

1. **Sketch.** In the sketch of the apparatus indicate the physical location of the origin used for the detector measurements. Use an arrow to indicate which direction is positive.

2. **Observe.** Sketch the results from the computer in the graph below. Carefully sketch a position-time graph for the vertical motion. Note that we will use the symbol \( y \) for positions along a vertical or \( y \)-axis.

3. **Interpret.** Label three events on the graph (1): the ball leaves the hand, (2) the ball at its highest position, and (3) the ball returns to the hand. Label the portion of the graph that represents upwards motion, downwards motion and the highest point in its trip. Indicate in which portions the velocity positive, negative, or equal to zero.

4. **Observe.** Sketch the results for the velocity-time graph from the computer. Make sure the events of the v-t graph line up vertically with the events of the y-t graph. Indicate on the velocity axis which direction is positive.

5. **Interpret** Label the same things as you did for the position-time graph.

6. **Reason.** How do these observations compare with your predictions regarding the nature of the upwards motion? Explain.

7. **Reason.** How do these observations compare with your predictions regarding the nature of the downwards motion? Explain.

8. **Interpret.** Is the ball’s acceleration as it rises the same or different from its acceleration as it falls? What do you conclude about the acceleration of a tossed ball?

9. **Reason.** Many people are interested in what happened when the ball “turns around” at the top of its trip. Some students argue that the acceleration at the top is zero; others think not. What do you think happens to the acceleration at this point? Use the v-t graph to help explain.

---

**Freefall** occurs when an object is travelling straight up or down under the influence of gravity alone. An object in freefall accelerates uniformly in the downwards direction the entire time – whether it is traveling upwards, downwards, or is at the top of its trip.

10. **Interpret.** On the two graphs above, label the interval of time during which the ball experiences freefall.
SPH3U: The Acceleration Due to Gravity

Last class we saw that an object in freefall accelerates uniformly due to gravity when air resistance is not a large factor.

A: The Acceleration Experiment

We need to find out what the rate of acceleration is and what that rate might depend upon. Each group will choose a test object, make measurements, calculate the acceleration of the object and as a class we will compare the results.

1. **Describe.** Choose a (non-lethal) object to drop down the stairwell. We want to measure the acceleration of gravity and minimize other effects that might get in the way. Describe your object and mention why it is suitable for our investigation.

2. **Represent.** Draw the set-up for your experiment, indicate and label all the quantities you will measure. Show your sign convention and coordinate system.

3. **Describe.** Briefly describe how you will carry out the experiment.

4. **Observe.** Collect your equipment, conduct the experiment and record all your measurements here.

5. **Calculate.** Find your acceleration value.

6. **Record.** State a final result. Record this result on the blackboard for the class discussion.
B: The Freefall Problem

Timothy, a student no longer at our school, has very deviously hopped up on to the roof of the school. Emily is standing below and tosses a ball straight upwards to Timothy. It travels up past him, comes back down and he reaches out and catches it. Tim catches the ball 6.0 m above Emily’s hands. The ball was travelling at 12.0 m/s upwards, the moment it left Emily’s hand. We would like to know how much time this trip takes.

1. **Represent.** Complete part A below. Indicate the \(y\)-origin for position measurements and draw a sign convention where upwards is positive. Label the important events and attach the given information.

2. **Represent.** Complete part B below. Make sure the two graphs line-up vertically. Draw a single dotted vertical line through the graphs indicating the moment when the ball is at its highest.

<table>
<thead>
<tr>
<th>A: Pictorial Representation</th>
<th>B: Physics Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketch, coordinate system, label given information, conversions, key events, unknowns</td>
<td>Motion diagram, motion graphs, key events</td>
</tr>
<tr>
<td>Event ①:</td>
<td></td>
</tr>
<tr>
<td>Event ②:</td>
<td></td>
</tr>
</tbody>
</table>

3. **Reason.** We would like to find the displacement of the ball while in freefall. Some students argue that we can’t easily tell what the displacement is since we don’t know how high the ball goes. Explain why it is possible and illustrate this displacement with an arrow on the sketch.

The total length of the path traveled by an object is the **distance**. The change in position, from one event to another is the **displacement**. Distance is a scalar quantity and displacement is a vector quantity. **For uniform motion only,** the magnitude of the displacement is the same as the distance.

4. **Reason.** The BIG 5 equations are valid for any interval of motion where the acceleration is uniform. Does the ball accelerate uniformly between the two events you chose? Explain.

5. **Reason.** Isaac says, “I want to use an interval of time that ends when the ball comes to a stop in Tim’s hand. Then we know that \(v_f = 0\).” Why is Isaac incorrect? Explain.
6. **Solve.** Choose a BIG five equation to solve for the displacement. (Hint: one single BIG 5 equation will solve this problem). Note that you will need the quadratic formula to do this! $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ For convenience you may leave out the units for the quadratic step.

**D: Mathematical Representation**

Complete equations, describe steps, algebraic work, substitutions with units, final statement

---

7. **Interpret.** Now we have an interesting result or pair of results! Why are there two solutions to this problem? How do we physically interpret this? Which one is the desired solution? Explain using a simple sketch.

8. **Interpret.** State your final answer to the problem.

9. **Solve.** How high does the ball travel above Emily? Indicate on the sketch your new pair of events for this problem.

**A: Pictorial Representation**

Sketch, coordinate system, label given information, conversions, key events, unknowns

**D: Mathematical Representation**

Complete equations, describe steps, algebraic work, substitutions with units, final statement
This exercise will help you put together many of the ideas we have come across in studying graphical representations of motion. Before completing the table, examine the sample entries and be sure you understand them. Note that some information may be found on both graphs. Now fill in the missing entries in the table below – describe how you find the information.

### How to get information from motion graphs

<table>
<thead>
<tr>
<th>Information sought</th>
<th>Position-time graph</th>
<th>Velocity-time graph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where the object is at a particular instant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The object’s velocity at an instant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The object’s acceleration (if constant)</td>
<td>Can’t tell</td>
<td>Compute the slope</td>
</tr>
<tr>
<td>Whether the motion is uniform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whether the object is speeding up</td>
<td>Check whether the curve is getting steeper</td>
<td></td>
</tr>
<tr>
<td>Whether the object is slowing down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whether the acceleration is constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The object’s change in position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The object’s change in velocity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from *Physics by Inquiry*, McDermott and PEG U. Wash, © John Wiley and Sons, 1996
SPH3U: The Great Physics Cart Contest!

Your task is to design a car-like device that will roll along the school hallway when released from rest.

The Contest:
1. Each cart will have three trials for judging.
2. The carts will compete in at least one of the following categories (you choose)
   a) Fastest (shortest time for a 5 m race)
   b) Furthest distance
   c) Stop on a line at a designated distance of 3 m away.

Design Criteria:
1. The cart must fit in your locker.
2. It must have a minimum of 3 wheels
3. The cart must be made of recycled or reused materials and not from pre-made toy cars.
4. The cart must be powered by an elastic band of some kind.
5. The cart must start on its own when released from a stationary position.

Groups:
This project may be done individually or in a pair. If this project is done as a pair, your group must complete the group work form on the opposite page.

Performance Analysis Report:
Your Performance Analysis Report will include a position-time graph for your cart based on the data you take using a ticker-tape timer or computer motion sensor. From your graph, determine your cart’s maximum speed. You will also time your car and give its average velocity for a 1 m trip, 2 m trip and 3 m trip. Your graph, measurements and calculations will constitute your performance report (only 1 or 2 pages in total!)

Advertisement:
To brag about your car and its results you must make a full page advertisement (8½ x11 in size) that shows your car and mentions at least one exciting competition result or piece of analysis.

Schedule:
Build your car as soon as you can! Two class periods are scheduled to conduct your analysis and compete. The cart will be handed-in on the last day of testing. The report and advertisement are due shortly afterwards.

Analysis date: ___________
Report and advertisement date: ___________

Please submit this page with your project!

You may not use the school shop for this project
**SPH3U: The Great Physics Cart Contest!**

Group Members:                      Total Mark:

**Quality and Design** – How well built and designed is the cart? (10 marks)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 4</td>
<td>Car barely functional, poorly designed, falls apart</td>
</tr>
<tr>
<td>5 - 6</td>
<td>Car has basic function, wheels well-attached, energy source adequate</td>
</tr>
<tr>
<td>7 - 8</td>
<td>Car rolls well, wheels aligned, good use of materials, reliable energy source</td>
</tr>
<tr>
<td>9 - 10</td>
<td>Car rolls very smoothly, clever use of materials, sturdy, powerful energy source, very consistent</td>
</tr>
</tbody>
</table>

**Performance** - How did it perform in a competition? (5 marks)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 2</td>
<td>Did not complete an event</td>
</tr>
<tr>
<td>3</td>
<td>Completed an event with adequate score</td>
</tr>
<tr>
<td>4</td>
<td>Completed an event with a good score</td>
</tr>
<tr>
<td>5</td>
<td>Completed or won an event with an outstanding score</td>
</tr>
</tbody>
</table>

**Advertisement** – Does it grab your attention? (5 marks)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 2</td>
<td>Important information missing, messy, little visual appeal</td>
</tr>
<tr>
<td>3</td>
<td>Basic, neat layout, contains required information</td>
</tr>
<tr>
<td>4</td>
<td>Interesting design and presentation, good use of information</td>
</tr>
<tr>
<td>5</td>
<td>Clever design and layout, eye catching, excellent use of information</td>
</tr>
</tbody>
</table>

**Performance Analysis Report** – Does it show a complete and accurate analysis? (5 marks)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 2</td>
<td>Important results missing or incorrectly completed</td>
</tr>
<tr>
<td>3</td>
<td>Graph adequate, basic results shown, minor errors</td>
</tr>
<tr>
<td>4</td>
<td>Neat, easy-to-read labelled graph, results carefully shown including units</td>
</tr>
<tr>
<td>5</td>
<td>Clear presentation of all analytical results</td>
</tr>
</tbody>
</table>

**Group Work Form**

Indicate with a checkmark which parts of the project each member worked on. Some parts may be shared.

<table>
<thead>
<tr>
<th>Name:</th>
<th>Name:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cart construction (include roughly how much time each)</td>
<td></td>
</tr>
<tr>
<td>Ticker-tape measurements</td>
<td></td>
</tr>
<tr>
<td>Timing measurements</td>
<td></td>
</tr>
<tr>
<td>Position-time graph</td>
<td></td>
</tr>
<tr>
<td>Analysis calculations</td>
<td></td>
</tr>
<tr>
<td>Advertisement</td>
<td></td>
</tr>
</tbody>
</table>
The main model of motion we have developed so far is uniform acceleration in a straight line. But the real world can be much more complex than this! When we walk, bike or drive, we change directions, hang a left, or go west. These are examples of two dimensional motion, or motion in a plane.

**A: Let’s Take a Walk**

When depicting two-dimensional motion we use vector arrows to represent each step in our journey. These vectors are drawn according to a scale and a coordinate system. You will need a ruler and protractor for this investigation.

1. Your friend walks 7 m south and then 5 m east. Illustrate this using two vector arrows, one after the other.

2. Remind yourself: What is the definition of displacement? Write it here.

3. Draw a single vector arrow which represents the total displacement for your friend’s entire trip.

4. Roughly speaking, in what direction does this new vector point? Explain how to use the diagram to determine the direction very carefully. Determine this now.

5. Explain how to use the diagram to determine how far your friend is from her starting point. Determine this now.

Writing down vectors in two dimensions becomes tricky. Our simple technique of using sign conventions will not easily work. We now use a special vector notation. Imagine someone travels 3.5 m in a direction North and 60° to the West. We will record this by writing: $\Delta \vec{d} = 3.5 \, m \, [N60^\circ W]$. The symbol $\Delta \vec{d}$ with an arrow signifies a displacement (a change in the position vector). The number part, 3.5 m, is called the magnitude of the vector. The angle that is used is always between zero and 90°, and is measured at the tail of the vector.

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6. Label the three vectors in your diagram as $\Delta \vec{d}_1$, $\Delta \vec{d}_2$, and $\Delta \vec{d}_3$, following the example described above including the magnitude, unit and direction.

7. The vector diagram we have drawn above is actually a picture of an equation where two quantities added together give a third quantity, the total. Write down the equation represented by your diagram.

Note that whenever vectors are added together to give a total, they are drawn tip to tail, just as you have done above.

### Part B: Distance Versus Displacement, Speed Versus Velocity

1. Remind yourself: What is the definition of distance? Write it here.

2. Determine the total distance your friend travels. Compare this with the magnitude of the total displacement. Explain why these quantities are different.

3. Give an example of a situation where the displacement of an object is zero, but the distance is not. Draw a diagram to help explain why.

4. We want to calculate your friend’s velocity during this trip. What type of velocity will this be: instantaneous or average? Explain.

5. Remind yourself: What is the definition of average velocity? What is the definition of average speed? Write these here.

6. Your stopwatch shows that it took your friend 11.0 seconds to make her trip. Calculate her average velocity and her average speed. Use the new vector notation for the velocity calculation.
1. Draw each vector to scale, each starting at the origin of the coordinate system.

\[ \vec{A} = 10 \text{ m [E]} \]
\[ \vec{B} = 25 \text{ m [N 30°W]} \]
\[ \vec{C} = 42 \text{ m [S 10° E]} \]
\[ \vec{D} = 35 \text{ m [W 70° S]} \]
\[ \vec{E} = 32 \text{ m [E 80° N]} \]

\[ \vec{A} = 15 \text{ km [D]} \]
\[ \vec{B} = 20 \text{ km [U 45°L]} \]
\[ \vec{C} = 50 \text{ km [R 15° U]} \]
\[ \vec{D} = 28 \text{ km [L 30° D]} \]
\[ \vec{E} = 31 \text{ km [U 80° R]} \]

2. Measure each vector according to the scale and coordinate system.
3. Find the total displacement for each trip by adding the two displacement vectors together tip-to-tail. Complete the chart assuming the whole trip took 1 h. Use the scale 1 cm = 10 km. Don’t worry if your vectors go outside the boxes!

<table>
<thead>
<tr>
<th>Vectors</th>
<th>Diagram</th>
<th>Total Displ.</th>
<th>Total Dist.</th>
<th>Avg. Velocity</th>
<th>Avg. Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 km [E] 30 km [E]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 km [E] 30 km [N]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 km [E] 30 km [W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 km [E] 30 km [E30°N]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 km [E] 30 km [S50°W]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SPH3U: The Vector Adventure

Mission
Your mission, should you choose to accept it (and you do), is to find the displacement and time for a trip from the threshold of the classroom to each location marked on the map.

Proof
As proof you (meaning each person) must construct a scale diagram for each path leading to the goal.

- Draw all paths one sheet of graph paper, starting at the same point.
- Make sure all final destinations will fit on the paper.
- Clearly show your coordinate system and scale (in metres).
- Each vector in the path must be accurately labeled.
- The total displacement should be drawn in a different colour, measured carefully and labeled.
- Time your walk back to the start.
- Create a chart on the reverse side of your diagrams giving the total distance, displacement, time, average speed and average velocity.

<table>
<thead>
<tr>
<th>Destination</th>
<th>Path</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: “No Food or Beverages” sign near staff room door</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B: Stage Crew Office Door</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: Jimi Hendrix Wall Painting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D: Wooden Shelf near Science Office</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A: The Tennis Ball Launcher!

1. In our video, we see a tennis ball launcher set-up in the back of a pick-up truck. The launcher can shoot tennis balls at 100 km/h. The truck will drive in the opposite direction at 100 km/h. When launched, how will the ball appear to move to a person standing beside the road? Justify your prediction.

B: Describing Relative Motions

For this investigation, you will need one piece of cloth and a physics buggy.

1. Place the stopped buggy on the cloth. Pull the cloth along the table. When you pull the cloth, be sure to hold it by two corners. Buggies must not fall to the floor! Two of your friends make seemingly contradictory observations: “The buggy is clearly moving” and “the buggy remains at rest”. Explain how each is correct, from a certain point of view.

When motion can result from more than one cause (for example, the buggy’s motor and the pulled cloth) then we must talk about the relative motion of the situation. We must describe how one object is moving relative to another object.

2. For the previous situation, describe the motion of the buggy relative to the table and the cloth. Describe the motion of the cloth relative to the table.

To label the velocities of an object involved in relative motion we will use a new notation. The symbol, $a \vec{v}_b$, represents the velocity of object $a$ relative to object $b$.

3. Write down the relative velocity symbols for the three possible velocities in the situation of a buggy moving on cloth moving on a table. Use the symbols $b$ for buggy, $c$ for cloth and $t$ for table. State in words the meaning of each symbol.

C: Combining Motions

Use colourful chalk to draw a starting point on the cloth near one end. In this next part we will make a series of predictions and test them using the buggy on the cloth. For each situation we will consider:
a) Draw two separate vector arrows that represent the velocity of the cloth and the velocity of the buggy on the cloth. Label these. Estimate the length of the vectors.
b) Predict how the buggy will move relative to the table. Give a simple description.
c) Try it out. Pull your cloth along with the moving buggy. Make sure someone is ready to catch it. **Don't let the buggy fall!**
d) Observe how the buggy moves relative to the table. Draw and label a velocity vector that represents this (the resultant velocity). How does this compare with your prediction?

**1.** In the first situation, the buggy will point in the same direction as the cloth’s motion and you will pull the cloth at a speed a bit slower than the buggy.

<table>
<thead>
<tr>
<th>Two velocity vectors</th>
<th>Predicted Motion</th>
<th>b \vec{V}_t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. This time the buggy will point in the direction opposite to the cloth’s motion and you will pull the cloth a bit faster than the buggy moves. **Don't let the buggy fall!** Complete the chart below.

<table>
<thead>
<tr>
<th>Two velocities</th>
<th>Predicted Motion</th>
<th>b \vec{V}_t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. How are the three velocity vectors that you have drawn related? Think of how can you combine or add two of the velocities to get the third.

Vectors of any kind can be added together (as long as they are all the *same* kind!). Just like we learned with displacement vectors, velocity vectors can be added by drawing them tip to tail. The total gives a *resultant velocity* or the combined velocity of the two motions.

4. Draw a vector diagram which shows how the vectors are added to give the total. If vectors overlap, draw one slightly below the other. Label your diagram.

5. Return to your prediction in question A#1. Recreate the situation using the buggy and cloth. Fill in the chart. We will make our observations from the video – move on while you wait for the video.

<table>
<thead>
<tr>
<th>Two velocities</th>
<th>Prediction</th>
<th>Observations from the video</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. An airplane makes a landing at an airport. The plane experiences a headwind (wind coming towards it) of speed equal to its own “airspeed”. How will this look to an observer standing on the ground?

D: Crossing the River
A river has a current which runs straight west. A swimmer, starting from the south shore, points herself due north and swims in the river. Use the symbols $s$ for the swimmer, $w$ for the water and $g$ for the ground.

1. (work individually) An observer on the shore watches the swimmer and measures her velocity. Predict what the observer will measure for the swimmer’s speed and direction. When your group members are finished, share and discuss your predictions.

2. (work together) Model this situation using the buggy and cloth. Draw a dot on the cloth with colourful chalk to indicate the swimmer’s starting point. Fill in the chart below:
   (a) Draw a visual diagram of the set-up clearly showing the orientation of the buggy.
   (b) Draw the velocity vectors for the swimmer relative to the water and the water relative to the shore.
   (c) Watch your swimmer move and illustrate the motion. Show the initial and final positions. Draw a single displacement vector.

<table>
<thead>
<tr>
<th>Visual diagram</th>
<th>Velocity vectors</th>
<th>Observed motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Did the swimmer travel straight across the river? Draw a velocity vector diagram and find the velocity of the swimmer relative to the shore. Use this to help explain the observed motion.

4. The swimmer really did want to travel directly across the river. How can she do this? Explain and fill in the chart below. Model this with your buggy and show your teacher.

<table>
<thead>
<tr>
<th>Visual diagram</th>
<th>Three velocity vectors</th>
<th>Observed motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
You are the pilot of a small aircraft leaving the Toronto Island Airport. After climbing to 12 000 ft you set the plane cruising with an airspeed of 400 km/h [W]. You are advised by ground control of strong winds and rough weather conditions.

Complete the chart to show the effect of different winds on your flight. For each situation draw a vector diagram for the velocities. Measure and label the resultant vector. Draw a scale vector diagram showing the path the plane follows and its displacement relative to the start in Toronto after 1 hour of travel. Indicate your scales. Use the symbols $p$ for the plane, $a$ for the air and $g$ for the ground.

<table>
<thead>
<tr>
<th>Wind</th>
<th>Velocity Diagram (1 cm = )</th>
<th>Position Picture (1 cm = )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 km/h [W]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 km/h [N]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120 km/h [E]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 km/h [S20°E]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
You are driving a boat across a river starting from Dock 1. The current runs due north at 2 m/s and the boat travels at 5 m/s relative to the water.

<table>
<thead>
<tr>
<th>Direction of Boat</th>
<th>( \vec{v}_b )</th>
<th>( \Delta \vec{d} ) after 10 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>[E]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[E 30° N]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[E 24° S]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. According to your chart which way should you point the boat if you wish to travel to the dock on the other side of the river?

2. In which situation do you have the largest velocity relative to the ground?

3. In which situation will you cross the river in the least time? Careful!

CHALLENGE! A sunbather, drifting downstream on a raft, dives off the raft just as it passes under a bridge and swims against the current for 15 min. She then turns and swims downstream, making the same total effort and overtaking the raft when it is 1.0 km downstream from the bridge. What is the speed of the current in the river? (Sir Isaac Newton Physics Competition, 1975)
A: What is Force?
What are forces and what role do they play in our understanding of how the world works? These are two big questions that we begin to answer today.

1. **Describe.** What is a force? Explain as if you were talking to a friend’s younger brother or sister. Give some suitable examples of forces.

B: Units of Force
Make sure every member of your group tries this activity! You will need: 2 identical elastics, two 10 N spring scales, and a ruler.

1. **Reason.** Loop one elastic around your two pointer fingers. Separate your fingers until the rubber band has a bit of stretch. You have now created your very own standard unit of force. Describe a method using the ruler that will allow other people to create the same amount of force. Give your unit of force a name (often in honour of its discoverer).

2. **Describe and Represent.** How does the feeling of force experienced by each finger compare? Draw an arrow representing the force each finger experiences starting from each finger on the diagram. (Don’t draw the elastic.)

3. **Describe and Represent.** Rest your fingers and try again using two elastics stretched to the same standard distance. Describe how the sensation of force on your fingers has changed. Draw arrows again and explain how you chose to draw their length.

When two objects affect one another we say that they interact. The two parts of this interaction are called forces. Intuitively, a force is a push or a pull of one object on another. Each force has a magnitude (how hard it’s pushing or pulling) and it has a direction. In our previous example, we say the two fingers are interacting with one another using an elastic.

4. **Reason.** What type of quantity best represents a force: scalar or vector? Explain.

C: Measuring Force
Rather than carry around a bag of elastics and a ruler, we will use a spring scale to measure the size of forces. Before you get your license to operate a spring scale, you need to know how to calibrate it. Hold the scale horizontally or vertically, just as you will use it when measuring, but without pulling on the hook. Adjust the scale (a sliding cover or nut at the top) so it reads zero. The scale reads in units called newtons whose symbol is N.

1. **Explain.** Why is it important to hold the spring scale with the same orientation as you would when making your measurement?
2. **Observe.** Create your standard unit of force but replace one finger with a spring scale. What is your unit of force equivalent to in newtons? Draw an arrow showing size and direction of the force on your finger and label it (for example, 3.1 N[left]).

3. **Predict.** When you replace your second finger with a second spring scale and hold the elastic to its standard length, what will each scale read? Explain your prediction.

4. **Test and Reason.** Now actually replace the second finger with a second spring scale and record the two readings. What is special about the two forces that make up this interaction? Would it be possible to have only one of these forces?

5. **Test.** In question B#3 you used two elastics and described how the feeling of the force changed. Test this situation with one spring scale. Does the result agree or disagree with the sensation you experienced? Explain.

---

In physics we simplify the real world in order to focus on the basic ideas. Instead of drawing a beautiful diagram of a hand each time, we will represent the hand using a *model*. In grade 11 we will model all our objects as a *point particle* – we imagine all the mass of the object compressed into a single point. The diagram we create is called a *force diagram*.

6. **Represent.** For the previous situation, draw a vector arrow representing the two forces acting on your finger due to each elastic. Start the vectors at the dot and draw them *tip to tail*. Label each vector.

---

**D: Combining Different Forces**

1. **Observe.** Find two different elastics. Stretch each individually to the same standard length and measure the force reading of each.

2. **Predict.** What will be the combined force reading of the two elastics stretched to the standard length between your finger and the spring scale? Draw the two separate force vectors *tip to tail*. Explain the idea behind your prediction. (We will soon develop this into a very powerful rule!)

3. **Test.** Stretch the two elastics together and measure the single, combined force. Does the result confirm your prediction? What does this tell us about combining forces?
SPH3U: What is the Effect of a Force?

What happens when a single force acts on an object? This is a tricky question that took very clever people about 2000 years to figure out. Now it’s your turn! (Don’t worry - it won’t take as long this time around.) In all the examples that follow, we will be examining the effect of a single, constant force.

A: The Steady Pull

1. **Prediction.** How do you think the dynamics cart will move when you exert a constant horizontal force (a steady push or pull) on it?

2. **Design.** You need a dynamics cart, some masses, one elastic and a ruler. Test and describe a technique that will allow you to exert a constant force on the dynamics cart using these materials. You should be able to do this for an interval of about four seconds (this is why the masses are helpful). Take your time doing this. (Hint: Think back to the activity from last class where you created a standard force.)

3. **Reason.** Isaac watches you demonstrate your cart technique and says, “I can’t tell if the force you are applying is actually constant.” What should Isaac carefully observe about your technique in order to be convinced?

*** Practice your technique until you are good at it! Demonstrate this for your teacher before going on.***

4. **Prediction.** If necessary, revise your prediction from question A#1 based on what you have observed. Use a dashed line to show what the position graph, velocity graphs and motion diagram might look like. Finally, draw an arrow representing your pulling force acting on the cart (remember we are modeling the cart as a point particle).

5. **Test.** Once you are very confident in your pulling technique, pull the cart on the track in front of the motion detector. Describe how your predictions compare with the computer results. Make any changes necessary to the diagrams above.

B: Release the Cart!

Pull the cart along the floor at a constant speed and then release it.

1. **Observe.** Describe the motion of the cart after it has been released.

2. **Represent.** Complete the motion graphs and diagrams on the next page. Label three events on each: (1) the cart starts moving with a constant velocity, (2) the cart is released, and (3) the cart comes to rest.

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3. **Test.** Use the cart on the track with the motion detector to verify your graphs above. Describe any differences you noticed.

4. **Reason.** Emmy says, “I think the cart slows down as the initial push runs out. I don’t see anything pushing or pulling on it after we let go which means no forces”. Marie says, “I bet there is a force causing it to slow down. I have evidence for this interaction – rub your hands together quickly and feel.” Who do you agree with? Explain.

5. **Reason and Represent.** Imagine we could change the cart and floor to reduce friction a bit. Explain how the motion of the cart after it is released would be different. Sketch a velocity graph for this imaginary situation and explain how it appears different from the previous velocity graph.

6. **Reason and Represent.** Now imagine we very carefully remove all sources of friction. After we release the cart, what would we observe in this very special situation? Sketch a velocity graph. In this situation what horizontal forces are acting on the cart?

7. **Observe.** (as a class) Describe the motion of the hover puck after it is released.

C: **Force and Motion Summary**

1. **Reason.** Describe the motion that results from an object experiencing the two situations listed in the chart below. This will soon become an important rule about the effects of forces!

<table>
<thead>
<tr>
<th>Situation</th>
<th>Resulting Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>One single, constant force</td>
<td></td>
</tr>
<tr>
<td>No forces at all (two possibilities!)</td>
<td>1)</td>
</tr>
<tr>
<td></td>
<td>2)</td>
</tr>
</tbody>
</table>

2. **Reason.** Isaac says, “Wait a minute – in reality, our cart experiences a little friction all the time. But we said there was only one force acting on it while it sped up - the one from our elastic. This means our conclusions about the effects of a single force might be wrong.” Do you agree or disagree with Isaac? Do you think our conclusions might be different if friction was completely zero? Explain.
A: Two Forces

Exert two equal forces on the cart, but in opposite directions.

1. **Observe.** Describe the motion of the cart. Record the size of the forces.

2. **Represent.** Draw a force diagram (FD) showing the horizontal forces. Label the forces (for example, \( F_1 = 3 \text{N\,right} \))

We can mathematically represent the total effect of all the forces acting on an object by defining a new quantity called the *net force*, which is the sum of the forces acting on the object. \( \vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \ldots \) Since there may be forces in more than one direction (horizontal and vertical) we will often describe the forces and the net force in a particular direction (\( F_{\text{net},x} \) or \( F_{\text{net},y} \)).

3. **Reason.** What is the net force experienced by the cart in the \( x \)-direction equal to?

4. **Reason.** We haven’t thought carefully about what forces may be acting on the cart in the vertical direction. Without worrying about the specific forces, what do you think the net force in the \( y \)-direction is equal to? Explain.

To calculate the net force we will change the vector equation for \( F_{\text{net}} \) into a *scalar equation*. We choose a sign convention and construct the scalar equation. Forces acting in the positive direction are labelled positive and forces acting in the negative direction are labelled negative. **The values of the force symbols are all positive.**

5. **Calculate.** Which force on your force diagram above is in the positive \( x \)-direction? Which is in the negative \( x \)-direction? Complete the scalar equation below for the net force in the \( x \)-direction by writing a positive or negative sign in front of the force symbol. Complete the calculation.

\[
F_{\text{net},x} = F_1 - F_2 = \text{______ N} \quad \text{______ N} = \text{______ N}
\]

**Check your results with your teacher before continuing**

In the future, if the first symbol in the expression for the net force is positive, we won’t write the positive sign. If the net force equals zero we say that the forces acting on the object are *balanced*. In part A the forces acting on the object in the \( x \)-direction are balanced.

C: Net Force Zero

The example in Part A demonstrated that an object initially at rest that experiences a net force of zero will remain at rest. What will happen to an object that is already moving which experiences a net force of zero?
1. **Represent.** Draw a FD for the cart your teacher has set up. Label the two forces. Note that the strings attached to the weights are pulling on the cart horizontally. Use the force values your teacher gives you.

2. **Calculate.** Write an expression for the net force in the x-direction and calculate the result.

3. **Prediction.** Your teacher will start the cart moving and then let go. Once released, the only horizontal forces acting on the cart will be those provided by the strings. How do you think the cart will move after being released?

4. **Test. (as a class)** Describe your observations. Do they confirm your prediction? Explain.

---

C: Net Force is Not Zero

This is another class demonstration. The only difference with the previous one is that one of the weights is a little bit larger.

1. **Represent.** Draw a FD and label the two forces. Use the values your teacher gives you.

2. **Calculate.** Write an expression for the net force and calculate the result.

If the net force is not equal to zero, we say that the forces acting on the object are *unbalanced.*

3. **Prediction.** How will the car move after it is released?

4. **Test. (as a class)** Describe your observations. Do they confirm your prediction? Explain.

5. **Predict.** According to your calculation for the net force, what single force could replace the two forces in this situation? Draw a FD for this situation. How does it compare with the previous FD?

6. **Test. (as a class)** The cart now experiences a single force equal to the net force from before. How does the motion of the cart compare with your previous observations?
The net force gives us the combined effect of all the forces acting on an object. The object behaves just as if a single force was acting on it that had the same magnitude and direction as the net force. Judging from only the motion of the object, we cannot tell the difference. We will call this idea the *net force principle*.

**D: Three Forces!**  
It is now time to return to your dynamics cart. Your challenge is to decide if two 2-N forces can balance a single 4-N force.  
(Make sure all your scales are pulling horizontally)

1. **Reason and Represent.** Decide how you will attach the scales and draw a FD. Label the forces.

2. **Calculate.** Write an expression for the net force and use your values to calculate the result.

3. **Reason.** Explain why you think you succeeded in this challenge.

**E: Conclusions – Forces and Motion**  
Complete the chart below based your understanding of forces and your observations thus far.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Net Force (circle one)</th>
<th>Resulting Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No forces at all</td>
<td>zero / non-zero</td>
<td>1)</td>
</tr>
<tr>
<td>Balanced forces (two or more)</td>
<td>zero / non-zero</td>
<td>1)</td>
</tr>
<tr>
<td>One single, unbalanced force</td>
<td>zero / non-zero</td>
<td>2)</td>
</tr>
<tr>
<td>Unbalanced forces (two or more)</td>
<td>zero / non-zero</td>
<td></td>
</tr>
</tbody>
</table>

1. **Reason.** Which situations above produce the same kinds of motion? What property do they have in common?

2. **Summarize.** Devise a rule that relates the net force with the resulting motion.
1. For each force diagram, write the expression for the net force in the $x$- or $y$-direction. Use the directions right or up as positive. Decide if the forces appear to be balanced or unbalanced. Based on our conclusions from the investigation, describe what type of motion you expect from these forces.

<table>
<thead>
<tr>
<th>FD</th>
<th>$\vec{F}_t$</th>
<th>$\vec{F}_f$</th>
<th>$\vec{F}_n$</th>
<th>$\vec{F}_a$</th>
<th>$\vec{F}_t$</th>
<th>$\vec{F}_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balanced?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F_{\text{net } x}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motion?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FD</th>
<th>$\vec{F}_t$</th>
<th>$\vec{F}_f$</th>
<th>$\vec{F}_n$</th>
<th>$\vec{F}_a$</th>
<th>$\vec{F}_t$</th>
<th>$\vec{F}_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balanced?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F_{\text{net } y}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motion?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Two forces act in opposite directions on an object, $F_t$ to the right and $F_f$ to the left. Indicate the direction of the acceleration with a wiggly acceleration vector. Compare the size of the two forces. Draw a force diagram.

<table>
<thead>
<tr>
<th>Motion Diagram</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>1</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compare</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force Diagram</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Each situation is described by a force diagram and an initial velocity. Draw a motion diagram for each situation.

<table>
<thead>
<tr>
<th>FD</th>
<th>$\vec{F}_t$</th>
<th>$\vec{F}_f$</th>
<th>$\vec{F}_a$</th>
<th>$\vec{F}_t$</th>
<th>$\vec{F}_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_f$</td>
<td>0</td>
<td>left</td>
<td>right</td>
<td>right</td>
<td></td>
</tr>
</tbody>
</table>

| Motion Diagram |   |   |   |   |   |   |
You kick a ball and watch it sail off. You toss a ball upwards and it reaches a great height. You push a cart along the ground and let go. There is no great surprise that it keeps traveling forwards for a while. But why does it continue moving forward? The answer to that question requires some careful thinking. Warm up those brain cells!

**A: Systems and Interactions**

Your teacher has a cart set up on a track with a motion detector and a force sensor. The cart glides very smoothly along the track so the force of friction is small enough to ignore. Our experiment has two parts. The first is when your teacher pushes on the cart using the force sensor and causes it to speed up. The second is after your teacher stops pushing and the cart moves on its own.

A system is the object or collection of objects we are interested in studying. At our level of physics, we will think of the system as a single object with the combined mass of all the objects inside. The environment is composed of the other objects outside of the system which interact with the system. Each interaction leads to one or occasionally two forces.

1. **Reason.** For today’s investigation the system is the cart and the collection of masses. In this experiment, what objects in the environment may be interacting with the system? (You should mention three.)

**B: When does the force start and stop?**

In this experiment there are three important events: (1) your teacher begins to push on the cart, (2) your teacher stops pushing on the cart, and (3) the cart reaches the end of the track.

1. **Predict.** Complete the graph showing your prediction for the velocity of the cart during the experiment. Use a dashed line. Label the three key events.

2. **Test.** Observe the results from the computer. Record the readings for the force probe showing your teacher’s push.

3. **Reason.** When does the interaction between your teacher (the force probe) and the cart end? How can you tell from the velocity graph?

4. **Represent.** Draw a FD for the system during the time interval between events 1 and 2. Include all three forces. Note that the interaction between the track and the cart leads to an upwards force. We will study this in more detail shortly. Include a separate wiggly vector showing the acceleration of the cart. Write an expression for the net force during each interval.

5. **Reason.** Marie says, “After our teacher stops pushing on the cart, the cart continues to move with a constant velocity. This is because the cart carries the pushing force with it.” Is there any evidence for an interaction that would produce a forwards force during the time interval between events 2 and 3? Do you agree or disagree with Marie? Explain.
A contact force is any force that only has a noticeable effect when two objects are in contact. When the force probe is in contact with the cart, and only then, is there evidence for a horizontal force. This force is an example of a contact force.

6. **Reason.** Use Newton’s 1st law to help explain what happens to the cart between events 2 and 3.

---

**C: Throw in the Towel**

Now we will repeat this experiment with one change – a piece of paper towel is taped underneath the cart such that it rubs on the track as the cart moves. Your teacher will push on the cart in a similar way as before.

1. **Reason.** The system is the cart, masses and towel. In this second experiment there are now four interactions. What are they? Do any of the interactions change during the experiment?

2. **Observe and Predict.** Watch as your teacher performs the experiment without collecting data. Draw your prediction for what you think the velocity and acceleration graphs will look like.

3. **Test and Explain.** Watch a second time and compare your predictions with the data. Is there any evidence for the presence of a force during the time interval between events 2 and 3?

4. **Reason and Represent.** Draw a FD for the cart for the interval of time between events 1 and 2. Explain how you decide to draw the lengths of the horizontal force vectors. Include an acceleration vector. Write an expression for \( F_{net} \).

5. **Reason and Represent.** Draw a FD for the cart for the interval of time between events 2 and 3. Explain how you decide to draw the lengths of the horizontal force vectors. Include an acceleration vector. Write an expression for \( F_{net} \).

6. **Reason.** Isaac has shown up late for class and is just joining in. He takes a look at FD 2-3 and makes a strange face. “The cart is moving forwards and only has a backwards force! That’s just impossible.” Explain to Isaac why the diagram and situation makes sense.

---

All matter has a special property called **inertia.** Because of this property when forces are unbalanced, it takes **time** for the velocity of the object to change. In some cases the time interval can be very small, but it is **never** zero. We will call this idea the **inertia principle.** The amount of time is related to the size of the net force and the amount of inertia (the mass).
A: The Falling Rock
Consider the situation shown to the right of a falling rock.

1. **Reason.** At this moment in time, what is interacting with the rock?

   **The Air Resistance Rule:** For our purposes, we will always assume there is no air resistance ($F_{air}$) unless it is mentioned in the problem or the situation does not make sense without it.

2. **Represent.** Draw the FD for the rock while it is falling. Show your choice of sign convention.

3. **Represent.** Write an expression for the net force in the $y$-direction.

B: The Rock Toss
A rock is tossed straight upwards. It is released from the hand and is still travelling upwards.

1. **Reason.** What is the rock interacting with at this moment in time?

2. **Represent.** Draw a FD for the rock while it is moving upwards. Include a wiggly acceleration vector.

3. **Represent.** Write an expression for the net force in the $y$-direction.

4. **Reason.** Isaac says, “How can something be travelling upwards when the only force acting on it is downwards? There must be an upwards force acting on the rock.” Do you agree or disagree? Explain.

5. **Reason.** Examine the two force diagrams for the two situations above. Explain what we cannot tell from a force diagram.

C. The Slowing Rock
A rock is being pulled by a string along a rough surface. It is gradually slowing down.

1. **Represent.** Draw a FD for the rock. Include an acceleration vector. Write an expression for net force in the $x$- and $y$-directions.

2. **Reason.** Compare the magnitudes of the forces in the horizontal and vertical directions. Explain your reasoning.
SPH3U: The Force of Gravity!

How does an object’s mass affect the size of the force of gravity it experiences? Let’s find out. You will need: one 10-N spring scale, a variety of masses, and some gravity.

1. **Reason.** Hang a mass from your spring scale. The system is the hanging mass. What objects from the environment are interacting with the hanging mass? What kind of forces do the interactions produce? Which is a contact force?

Any force that has an effect even when the objects are not in contact is called a **non-contact force**.

2. **Reason.** Is gravity a contact force or a non-contact force? How could you demonstrate this?

3. **Represent.** Draw a FD for the hanging mass. Explain why we can use the scale reading (an upwards force of tension) to determine the size of the force of gravity.

4. **Design.** We want to find out how the magnitude of the force of gravity depends on the mass of the object. Describe how you will conduct a simple experiment to collect data and determine this.

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>Force of Gravity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

5. **Observe.** Record your data in the chart.

6. **Analyze.** Decide which variable is the dependent one. Plot your data on the graph. Use the shape of the graph to describe how the force depends on the mass.

7. **Calculate.** Determine the slope of your graph, including units. Show your work on the graph.

8. **Analyze.** Write an equation for your line of best fit – use the symbols $F_g$ and $m$.

9. **Apply.** Use your new equation to determine the size of the force of gravity acting on a $1.5 \times 10^3$ kg car.
A: A Mysterious Force

Your friend places her backpack on a table. The backpack is the system.

1. **Reason.** What objects from the environment are interacting with the system?

2. **Reason.** Your friend draws a FD for the system and says, “I’m really not sure that there should be an upwards force.” Convince your friend. Cite direct evidence about the system that you can readily observe.

3. **Reason.** The backpack has a mass of 5.8 kg (all those textbooks). What is the size of the upwards force? Complete her original FD.

---

When two objects are in contact, they interact and exert normal forces on one another. A normal force (F_n) is a contact force that is always perpendicular to the surfaces at the point of contact. This force usually prevents objects from deforming much, breaking or simply merging together.

B: Evidence for the Normal Force

For these activities you need two metre sticks, a spring scale and a 500 g mass. Make a bridge using the metre stick between two tables. Gently press downwards with your finger in the middle of the metre stick.

1. **Observe.** Describe what you observe happening to the “rigid” metre stick. Why is the shape changing?

2. **Reason.** Describe the evidence for an upwards force acting on your finger (give one observation and one sensation).

3. **Observe.** Place the 500 g mass on the metre stick. Describe what happens. What is the size of the upwards normal force?

4. **Observe.** Remove the mass. Place the second metre stick directly on top of the first (the “table” is now twice as thick). Place the 500 g mass on top of the two sticks. What is different about the effect of the mass on our thicker “table”? How has the upwards normal force changed? Explain.

---

**Check with your teacher before proceeding.**
5. **Reason.** Imagine many, many metre sticks stacked up (a very thick table). What would happen to the metre sticks if we place the 500 g mass on top of them? How has the size of the upwards normal force changed compared to the one metre stick situation? Explain.

6. **Reason.** We are using the metre sticks to model the surface of a solid object. What is happening inside any object that is in contact with another in order to produce normal forces? Make a guess and quickly move on.

---

**C: The Measuring the Normal Force**

Rest your hand on the table and place the 500-g mass on the flat palm of your hand.

1. **Reason.** What is the size of the upwards normal force on the mass? Explain.

2. **Prediction.** Another member of your group will exert a 3 N force upwards on the mass. Draw a FD for this situation. What do you think will happen? How do you think your hand will feel? What will the size of the normal force be? Explain.

3. **Test.** Attach a spring scale to the mass and exert a 3 N force upwards. How did the sensation in your hand change? What force or forces do you think have changed size due to the upwards force?

---

The magnitude of the normal force depends on how hard the objects are pressing against one another. Other forces and motion may affect the size of a normal force. As a result, we always have to find the size of the normal force by analyzing the other forces acting on the system.
1. A child throws a very bouncy ball which hits a wall and then the ceiling. Draw a FD for the ball while it is (a) in contact with the wall and (b) in contact with the ceiling.

<table>
<thead>
<tr>
<th>Sketch</th>
<th>FD</th>
<th>Sketch</th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Wall Sketch" /></td>
<td><img src="image2" alt="Wall Force Diagram" /></td>
<td><img src="image3" alt="Ceiling Sketch" /></td>
<td><img src="image4" alt="Ceiling Force Diagram" /></td>
</tr>
</tbody>
</table>

2. A 0.5 kg book is at rest on top of your friend’s outstretched hand.
   a) Draw a FD for the book.
   b) Determine the size of the normal force.
   
   ![Hand Sketch](image5)  
   ![Hand Force Diagram](image6)

   c) Your friend’s hand is moving upwards and speeding up. Draw a motion diagram and force diagram for this situation. How have the forces on the book changed?

   ![Upward Motion Diagram](image7)  
   ![Upward Force Diagram](image8)

   d) Your friend’s hand is still moving upwards but is now slowing down. How have the forces on the book changed? Explain.

   ![Slowing Motion Diagram](image9)  
   ![Slowing Force Diagram](image10)

   e) The net force is 3.0 N [upwards]. Determine the size of the normal force acting on the book.

3. Your friend places the same book on a table and leans on top of it, pushing down with 12 N of force. Draw a FD for this situation. How has the upwards normal force of the table on the book changed? What is the size of this normal force?
What factors affect the acceleration of an object? We have already hinted that force and mass are key. Today’s investigation will help you understand how these quantities affect the acceleration.

Your group will use the carts and masses set up in the classroom. A motion detector will help track the velocity of the cart. Complete all the questions below before beginning the experiment and show this page to your teacher.

A: The Atwood Machine

1. **Reason.** Why does each mass, \( m_A \) and \( m_B \), move when released. What forces cause the acceleration of each mass?

2. **Reason.** When the mass, \( m_A \), is released how much mass is moving in total?

3. **Reason.** We can think of the two masses as a single system. What single force is the ultimate cause of the motion of the entire system (\( m_A \) and \( m_B \) together)? This is the force we will vary in our experiment.

4. **Reason.** To conduct a scientific investigation one must always change only one quantity and measure the results while ensuring that everything else remains unchanged. Suppose you want to increase the force moving the system while keeping everything else the same. You add 200 g to \( m_B \). What else **must** you do?

B: Investigating the Effects of Force

In the first experiment you will vary the force while keeping all other properties constant, to determine the effect of the net force on the acceleration. The computer will produce a velocity-time graph for you to analyze.

1. **Design an Experiment.** Describe how you will conduct your experiment. Show your teacher when you are ready.

** check with your teacher before continuing **
2. **Observe.** What is the total mass of your system \((m_A + m_B)\)? Remember, you must keep this constant!

3. **Observe.** Conduct the experiment and record your results in the chart below. Make fairly large changes in the masses (about 200 g). If \(m_B\) becomes too large the motion detector may have difficulty making measurements.

<table>
<thead>
<tr>
<th>(m_A) (kg)</th>
<th>(m_B) (kg)</th>
<th>System Mass (kg)</th>
<th>Net Force (N)</th>
<th>Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

4. **Represent.** Construct a graph of your results with the **force on the vertical axis**. Draw a line of best fit. This is done to assist with our later calculations.

5. **Interpret.** Use the pattern in your graph to help explain how acceleration depends on force.

6. **Calculate.** Determine the slope of the line of best fit. Show your work.

7. **Interpret.** Is the value of the slope close to any other quantities which describe our system? What do you think the slope physically represents about the object?

8. **Represent.** Write an equation for the line on your graph. Use symbols for net force and acceleration.

9. **Reason.** If we double the force acting on the system, what will happen to the acceleration?

10. **Reason.** If we reduce the force to one third, what will happen to the acceleration?
C: The Effect of Mass on Acceleration
This is a quick investigation what will help us to determine how changing the mass of the system, while keeping the net force constant, will affect the acceleration.

1. **Design an Experiment.** We want to double the mass of the system and keep the net force constant. Choose your original values and changed values for $m_A$ and $m_B$ that will accomplish this. Keep in mind the actual mass of the cart as you do this.

<table>
<thead>
<tr>
<th>Original</th>
<th>Changed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_A$:</td>
<td>$m_A$:</td>
</tr>
<tr>
<td>$m_B$:</td>
<td>$m_B$:</td>
</tr>
<tr>
<td>System mass:</td>
<td>System mass:</td>
</tr>
<tr>
<td>Net force:</td>
<td>Net force:</td>
</tr>
</tbody>
</table>

2. **Observe.** Use the Atwood machine and motion detector to conduct your investigation. Record your results below.

<table>
<thead>
<tr>
<th>Original</th>
<th>Changed</th>
</tr>
</thead>
<tbody>
<tr>
<td>System mass:</td>
<td>System mass:</td>
</tr>
<tr>
<td>Acceleration:</td>
<td>Acceleration:</td>
</tr>
</tbody>
</table>

3. **Find a Pattern.** Roughly speaking what happened to the value of the acceleration when you doubled the mass?

4. **Reason.** What do you think the acceleration would be if you were able to reduce the original system mass by half? Explain.

D: Conclusions
1. **Summarize.** How does a system’s acceleration depend on the net force?

2. **Summarize.** How does a system’s acceleration depend on the system mass?

3. **Speculate.** Create an equation that shows the relationship between the net force ($F_{net}$), the mass ($m$) and the acceleration ($a$) of a system.
**SPH3U: Representing Forces Homework**

Complete the chart for each situation. In some cases, there is more than one possible correct answer.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Sketch</th>
<th>Motion Diagram</th>
<th>Force Diagram</th>
<th>Newton’s 2nd Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A rock has a book resting on top of it.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>System = rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A tasty chocolate in your hand is moving upwards and is slowing down as it</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>approaches your mouth.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>System = chocolate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>System = Physics text</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>You hold a bag of groceries by the handle while standing in an elevator</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>that starts from the ground floor and speeds up.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>System = bag</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. **The Jumping Child.** (a) A 29.0 kg child is standing on the ground. Draw a FD for the child and a FD for the earth. Find the magnitude of each force. (b) The child jumps into the air. Draw a FD for the child and the earth while the child is in the air.

<table>
<thead>
<tr>
<th>Standing</th>
<th>Jumping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child</td>
<td>Earth</td>
</tr>
</tbody>
</table>

2. **Bicycle Collision!** A car (1200 kg) initially travelling at 40 km/h crashes into a bicycle (17 kg) that is initially at rest. During the collision, the car and bicycle interact and exert a 258 N force on each other for 1.1 seconds. You may assume all friction forces are negligible. (a) Find the acceleration of each object. (b) What is the speed of each object after the collision? Solve this problem on a forces homework sheet.

After you solve the problem answer: Even though the interaction forces are the same size, why are the results of the collision (the accelerations and the velocities) so different for the two objects? Give two reasons.

3. **Car Collision!** A car (1200 kg) moving at 11 m/s collides with a parked car (1200 kg). As a result of the collision, the moving car comes to a stop. During the 0.70 second collision the cars exert forces on each other and the parked car experiences an additional force of friction of 15600 N. (a) Find the acceleration of each object during the collision, and (b) determine how far the parked car moved. Solve this problem on a forces homework sheet.

After you solve the problem answer: Even though the interaction forces are the same size, why are the results of the collision (the accelerations) so different for the two objects?

Answers: (1) 284.2 N, 284.2 N, 284.2 N, (2) -0.22 m/s², 15 m/s², 39 km/h, 59 km/h, (3) 16 m/s², 2.7 m/s², 0.76 m
SPH3U: Force Problem Solving

Forces help us to understand why things move the way they do. Newton’s 2nd Law, \( F_{\text{net}} = ma \), is the law of cause and effect: it relates the causes of motion (forces) with the effects (acceleration). As a result, any problem that involves both force and motion will likely use the 2nd law. To understand the force side of the equation we use force diagrams and calculate the net force. To understand the acceleration side we use motion graphs and the BIG 5 equations.

A: The Elevator
An elevator and its load have a combined mass of 1600 kg and experience a force of gravity of 15680 N. It is initially moving downwards at 12 m/s. Find the tension in the supporting cable when the elevator is brought to rest with a constant acceleration in a distance of 42 m. Complete the parts of our solution process below.

1. **Explain.** How did you choose your key events?

2. **Describe.** While it is slowing down, what is the elevator interacting with?

C: Word Representation
Explanation of physics: why, how? Assumptions

D: Mathematical Representation
Complete equations, describe steps, algebraic work, substitutions with units, final statement

© C. Meyer 2012
B: Sample Problems

Use your solution sheets to answer the following questions.

1. **Stopping a Neutron.** When a nucleus captures a stray neutron, it brings the neutron to a stop in a distance equal to the diameter of the nucleus by means of the strong force. A stray neutron with an initial speed of $1.4 \times 10^7$ m/s is captured by a nucleus with diameter $d = 1.0 \times 10^{-14}$ m (the stopping distance). Assuming that the strong force on the neutron is constant, find the magnitude of that force. The neutron's mass is $1.67 \times 10^{-27}$ kg.

2. **Sunjamming.** A "sun yacht" is a spacecraft with a large sail that is pushed by sunlight. Although such a push is tiny in everyday circumstances, it can be large enough to send the spacecraft outward from the Sun on a cost-free but slow trip. Your spacecraft has a mass of 900 kg and receives a push of 20 N. It starts from rest near the earth. How far will it travel in 1.0 days and how fast will it then be moving?

3. **Two People Pull.** Two people are having a tug-of-war and pull on a 25 kg sled that starts at rest on frictionless ice. The forces suddenly change as one person tugs harder with a force of 92 N compared with 90 N. How quickly is the sled moving after 1.5 s?

4. **Take Off.** A Navy jet with a mass of $2.3 \times 10^4$ kg requires an airspeed of 85 m/s for liftoff. The engine develops a maximum force of $1.07 \times 10^5$ N, but that is insufficient for reaching takeoff speed in the 90 m runway available on an aircraft carrier. What minimum force (assumed constant) is needed from the catapult that is used to help launch the jet? Assume that the catapult and the jet's engine each exert a constant force over the 90 m distance used for takeoff.

5. **Elevator.** An elevator has a mass of 2840 kg. What is the tension when the elevator is slowing at the rate of $1.22$ m/s$^2$ but is still moving upward?

Answers: (1) 16 N, (2) $8 \times 10^4$ km, $2 \times 10^3$ m/s, (3) 0.12 m/s, (4) $8.2 \times 10^4$ N; (5) 24.4 kN

---

Adapted from Cummings, K., et al, *Understanding Physics*. Wiley, 2004
### A: Truck vs. Car!

1. **Predict.** (*Individually*) Imagine a car and a truck push on one another or collide. We want to explore the forces that arise in a few of these situations. For each situation consider two possible forces: the force the truck exerts on the car, $\vec{F}_{T-C}$, and the force the car exerts on the truck, $\vec{F}_{C-T}$. Decide based on the situation, whether each force is present and, if both are, compare their magnitudes. When finished, record your results on the board.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Exists?</th>
<th>Compare (&lt;, &gt;, =)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) A truck pushes a stalled car from behind. They move together at a constant velocity.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) A fast moving car hits a truck at rest.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) A fast truck hits a car at rest.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) A truck tows a car. They are speeding up together.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. **Explain.** Why, according to common sense, someone might decide that, in example (c), the truck exerts the greater force.

### B: Analysis - Kinematics

Consider the collision between a quickly moving truck and a car at rest, example (c) from part A. We will model this with a large and small dynamics cart (500 g, 250 g). To the right is a graph showing the $v$-$t$ data for each throughout the collision. The positive direction is to the right.

1. **Explain.** How can we tell that the dotted vertical lines correctly represent the starting and ending moments of the collision?

2. **Interpret.** What is the duration of the collision?

3. **Calculate.** Use the velocity information to find the average acceleration (including direction) of each cart during the complete collision. Show all your work.
4. **Explain.** Which cart experienced the greater acceleration? Is this surprising? Describe, in an intuitive way, why this seems reasonable.

5. **Reason.** Imagine the carts were vehicles in a collision. Which one would you prefer to be in? Explain.

---

**C: Analysis - Forces**

It is clear from the data and your calculations that the small cart reacts more during the collision – its acceleration is the greatest. But this is not the end of the story. Acceleration is the result of force, and we have not yet found the forces responsible. In this collision, the forces the carts exert upon one another are much larger than the force of friction. Therefore it is reasonable to ignore friction and assume that there is only one important horizontal force acting on each cart.

1. **Represent.** Draw a FD for each cart showing the horizontal forces. Label the forces \( \vec{F}_{L-S} \), meaning the force of the large cart on the small cart, and \( \vec{F}_{S-L} \), meaning the force of the small cart on the large cart.

2. **Calculate.** Find the magnitude of the forces on your FDs using your acceleration results. Watch the signs!

3. **Explain.** How does the magnitude of \( \vec{F}_{L-S} \) compare with \( \vec{F}_{S-L} \)? Is this result surprising? Why?

4. **Interpret.** The force results seem like a contradiction of our common sense. We must re-interpret what our common sense is actually telling us. When we observe a collision between a car and truck, are we observing forces or accelerations? Explain.

5. **Explain.** Another strange aspect of this result is that forces of equal size produce such different acceleration results. How is this possible?

---

**D: Test this Idea**

1. **Challenge.** Your teacher will use force probes to measure the two interaction forces of the car and truck (the two carts). Come up with a situation where you think the two forces are not the same.
SPH3U: Newton’s Third Law

The case we have just studied of colliding carts points to a very general law about forces. The idea that the interaction forces between two objects (the carts) are equal in size holds true for all physical objects. This idea is known as Newton’s 3rd Law.

When objects interact, a pair of forces is always produced – they are two parts of one interaction. We call these two forces a third law force pair. The two forces that are members of the same third law pair share some important characteristics.

- the same magnitude
- opposite directions
- the same type (gravitational, normal, tension, etc.)
- start and stop acting at the same time
- act on different objects

We can use the 3rd law notation for forces to help show these relationships. \( \vec{F}_{n \text{ car-\text{truck}}} \) means the force of gravity experienced by a ball due to the earth. According to Newton’s 3rd law, the partner to this force in a 3rd law pair is \( \vec{F}_{n \text{ truck-\text{car}}} \).

A: Return of the Elastic Bands!

We first encountered the idea of 3rd law pairs in our first lesson on forces – the one with the all elastic bands. If your memory is a bit foggy, flip back to that investigation as you answer the following questions.

1. **Describe.** We had an elastic band stretched between two fingers. How did the forces experienced by each finger compare?

2. **Represent.** Draw a FD for each finger and use the 3rd law notation to label the forces. The interaction between your fingers is an elastic interaction.

3. **Reason.** Is it possible in this situation for one finger to feel a force while the other finger does not? Explain.

4. **Reason.** Imagine we hook one end of the elastic around our finger and the other to the back of a truck. We stretch our elastic and to the standard length. How would the elastic force experienced by your finger compare with the elastic force experienced by the truck?

B: The Apple and the Earth

The story goes that our friend Sir Isaac Newton made a great discovery while he was sitting under an apple tree and an apple happened fall down on him.

1. **Represent.** Draw a FD for the apple while it is at rest on the ground. Label each force using the 3rd law notation.

2. **Reason.** Emmy says, “The two forces on the FD must be third law pairs - they are equal in magnitude and opposite in direction.” Do you agree or disagree? Explain.
3. **Represent.** Draw a FD for the apple and the earth *while the apple is falling.*

4. **Reason.** Marie says, “I think both the apple and the earth should be accelerating.” Do you agree or disagree? Explain.

5. **Reason.** Isaac says, “The earth clearly doesn’t move, so I don’t believe that it experiences an equal force to the apple.” Do you agree or disagree? Explain.

6. **Calculate.** The apple has a mass of 0.2 kg. What is the magnitude of the force of gravity it experiences? Actually calculate the apple’s acceleration using Newton’s 2nd law.

7. **Calculate.** The earth has a mass of \(6.0 \times 10^{24}\) kg. What is the magnitude of the force of gravity it experiences? Actually find the resulting acceleration.

8. **Explain.** Based on your results from the previous questions, why is it understandable that most people think that the earth does not experience a force due to the apple, just like Isaac.

---

**C: Physics on Ice**

You have brought your little cousin out staking for the very first time. Both of you are standing on the ice wearing skates (no friction) and are facing one another. Your little cousin is a bit timid and needs to hold on to your scarf.

1. **Represent and Calculate.** She holds on while you gently pull the scarf with a 6 N force to start her moving. Her little mass is 17 kg. Draw a FD for her and determine her speed after pulling for 2.0 s.

2. **Reason.** Albert says, “I understand why the cousin speeds up – you are pulling on the scarf and she holds on. But I don’t predict you will move. Your cousin is only holding on, not pulling. And, in any case, she is much smaller so she couldn’t pull you anyways.” Do you agree or disagree? Explain.

3. **Represent and Calculate.** Draw a FD for yourself on the ice with your cousin. Use your actual mass to determine your speed after the same 2.0 seconds of pulling.
Athletes are paid millions of dollars every year to endorse fancy shoes. Perhaps they do have some expertise in the matter – maybe the shoes do have an effect on their performance. What makes for a superior shoe? Perhaps it has something to do with friction!

**A: Shoe Friction**
1. **Reason.** Do you think an athlete wants their shoes to have lots of friction or little? Explain.

2. **Reason.** There are many types of shoes (or footwear) in the world. Which ones do you think have lots of friction? Which have little?

**B: The Types of Friction**

At the front of the class your teacher has a fairly heavy object and force sensor. Watch as your teacher will gradually exert a larger force on the object using the spring attached to a sensor until the object starts to move. No data will be collected yet.

1. **Represent.** For each situation below draw a force diagram for the object. Compare the size of the horizontal forces that may be involved in a particular situation.

<table>
<thead>
<tr>
<th>(A) Your teacher is not pulling on the object</th>
<th>(B) Your teacher is pulling, but it is not yet moving</th>
<th>(C) Your teacher is pulling and it is now moving at a constant velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD</td>
<td>FD</td>
<td>FD</td>
</tr>
</tbody>
</table>

   Compare:                                      Compare:                                     Compare:

2. **Reason.** In which situations above is the force of friction present? What evidence is there? Explain.

3. **Observe.** (as a class) Your teacher will now pull on the object while the computer records the data. Sketch a simplified version of the force data on the graph to the right and label the event when the object begins to move.

4. **Describe.** What happens to the size of the friction force when the object begins to move?
Friction is a contact force that occurs when two objects that are pressed together try to slide against one another. If the surfaces are sliding relative to one another we call the force kinetic friction ($F_{fk}$). If the two surfaces are not slipping we call the force static friction ($F_{fs}$).

5. **Describe.** Label the force diagrams above with the appropriate type of friction.

6. **Reason.** What would happen to the size of the force of static friction if we pulled a bit harder and the object still did not move? Explain.

The size of the force of static friction can take a range of values depending on what is happening in the particular situation. $0 < F_{fs} \leq F_{fs\text{ max}}$. There is a maximum possible value for the force of static friction which occurs just before the objects begin to slip. This maximum value is usually greater than the force of kinetic friction.

**C: Shoe Physics**

One member of each group must volunteer a shoe for this investigation. If you continue this work tomorrow, be sure to wear the same shoes!

1. **Predict.** (as a class) Hold up your group’s shoe. Take a look at the other groups’ shoes. Which shoe do you think will have the most kinetic friction?

2. **Reason.** What factors do you think might affect the amount of kinetic friction between the shoe and the floor? How do we make this a fair comparison?

**D: Kinetic Friction and the Normal Force**

To test our shoes, we need to answer an important question: How does the size of the force of kinetic friction depend on how hard the objects are pressing against one another?

1. **Reason.** Which force represents how hard the two objects are pressing against one another? In the case of your shoe, how do we find its size? Explain.

2. **Design an Experiment.** Use a spring scale, your group’s shoe and some masses. Describe the procedure of an experiment that will answer the question above. Draw a force diagram for your experiment.
3. **Observe and Represent.** Collect data according to your procedure. Plot the data comparing the forces on the graph.

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>$F_n$ (N)</th>
<th>$F_f$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

4. **Find a Pattern.** Describe how the size of the force of friction depends on the size of the normal force.

5. **Analyze.** Construct a line of best-fit for your data. Determine the slope of the line. Show your work below.

6. **Interpret.** The value you found for the slope is called the *coefficient of kinetic friction* ($\mu_k$). What characteristics of your experiment do you think affect this value? What is this value a measure of? What would a smaller value for $\mu_k$ signify?

7. **Analyze.** Write down an equation for the line of best fit for your graph. Use the symbols $F_n$, $\mu_k$ and $F_f$.

8. **Predict.** Make a prediction. If a 230 lb (1 kg = 2.2 lbs) basketball player wore your shoe (which may defy other laws of physics!) what would the force of kinetic friction be? Show your work.

9. **Report.** Record the results of your analysis for your shoe on a white board. Include your coefficient result and the previous prediction. Once the class is ready we will share these results. Move on for now.
E: How the Surfaces Affect Kinetic Friction

1. Speculate. Why do you think there is friction between two surfaces?

2. Predict. What kinds of surfaces will produce little friction and what kinds will produce great friction?

In the next experiment you will investigate what combination of surfaces will produce the most friction. Make sure that you use a fairly clean surface, otherwise you will be measuring the forces from grinding dirt. Draw the shoe with a bit of extra mass over four surfaces (table, glass, floor, one more of your choice).

3. Observe. What is the total mass of your shoe?

4. Predict. Choose your fourth surface. Which surfaces do you think will yield high, medium or low friction?

<table>
<thead>
<tr>
<th>Lower Surface</th>
<th>Prediction</th>
<th>Force of Friction ($F_f$)</th>
<th>Normal Force ($F_n$)</th>
<th>Coefficient ($\mu_k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Observe. Measure the force of friction in each case. Record your results in the chart above.

The coefficient of kinetic friction ($\mu_k$) depends on the physical properties (roughness, chemical composition) of the pair of surfaces and is related to the force of friction by the expression: $F_f = \mu_k F_n$. Since the force of kinetic friction is usually different from the maximum force of static friction, there is a separate coefficient of static friction ($\mu_s$). We can find the maximum force of static friction using the expression: $F_{f,\text{max}} = \mu_s F_n$.

6. Calculate. Find the coefficient of kinetic friction for the combination of surfaces in your experiment and add these to the table.

7. Describe. Were there any surprising results? What does this imply about the floors of professional basketball courts?

8. Calculate. Kobe Bryant comes charging down the basketball court, running at 6.3 m/s. He tries to stop moving and ends up sliding along the floor for 2.7 m. What is the coefficient of kinetic friction for his shoes+basketball court floor? Complete this problem on a forces homework sheet.
SPH3U: Representing Forces and Motion

This review activity presents four different situations. Your goal is to describe the forces and motion involved in each using a variety of different representations. You will do this by completing the missing information in each box.

1. A car is being towed by a tow truck which exerts a horizontal force. Both are speeding up after being stopped at a red light. The car experiences friction.

<table>
<thead>
<tr>
<th>A: Pictorial Representation</th>
<th>B: Physics Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketch, coordinate system</td>
<td>Motion diagram, motion graphs, force diagram</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C: Word Representation</th>
<th>D: Mathematical Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation of physics: why, how? Assumptions</td>
<td>Expressions for $F_{net,x}$ and $F_{net,y}$, compare the size of the forces involved</td>
</tr>
</tbody>
</table>

2. A child pulls an old rusty wagon along the sidewalk at a steady speed. The handle is level with the ground.

<table>
<thead>
<tr>
<th>A: Pictorial Representation</th>
<th>B: Physics Representation</th>
</tr>
</thead>
<tbody>
<tr>
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<tbody>
<tr>
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<td>Expressions for $F_{net,x}$ and $F_{net,y}$, compare the size of the forces involved</td>
</tr>
</tbody>
</table>
A group of friends is pushing a heavy stalled car, slowing it down as it rolls on a level driveway. It experiences friction.

<table>
<thead>
<tr>
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<th>B: Physics Representation</th>
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</tr>
</tbody>
</table>

4. A woman rides in an elevator that is slowing down after traveling up to the 16th floor of her apartment building.

<table>
<thead>
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<th>B: Physics Representation</th>
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</tr>
</tbody>
</table>
SPH3U: Physics Idol!

Group Members: ________________________________________________________________

Physics Topic: __________________________________________________________________

Desperate for fame, you and a group of your colleagues have decided (yes, you have) to enter this year’s Physics Idol competition! Choose a topic or problem from the unit on forces, create a song or video (with or without singing) that explains it and submit your work to the judges (your teacher) and wait for the lucrative career opportunities to roll in!

Criteria - The judges will be looking for:
- An in depth understanding of a physics concept or problem from the force unit
- The song lyrics should be between two to four minutes long (guitar solos don’t count!)
- The video should be between three and four minutes long
- All lyrics and script for the video must be appropriate for a classroom (no foul language, etc.)
- You may work individually, or in a group of two or three

Hand-in
- A CD or mp3 with your song; or a DVD or WMV (windows media video format) compatible file
- Alternately, instead of submitting a CD or mp3, the song may be performed live in class
- A simple handout with your lyrics to the song or the script for the video
- This evaluation page (an extra copy can be printed out from the course website if needed)

Evaluation

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>States few main points and details that focus on the topic or information does not relate to topic.</td>
<td>States most of the main points and details that focus on the topic. May include some unnecessary information.</td>
<td>Adequately states the main points and details that are accurately focused on in the topic</td>
<td>Thoroughly and clearly states the main points and precise details of the topic.</td>
<td>/10</td>
</tr>
<tr>
<td>Organization</td>
<td>Little or no attempt is made to stay on the topic or follow a logical flow of information. Presentation is not well organized or deviates far from intended topic. Does not consider audience. Difficult to understand / follow.</td>
<td>Delivers the information in a fairly logical manner but does not stay on the topic. Little consideration of audience. Some information was peripheral to the project or use of incomplete thoughts/ideas.</td>
<td>Adequately delivers the information in a logical sequence while staying on the topic and considering the audience. Speaks clearly and confidently about topic. Information was covered in a satisfactory manner.</td>
<td>Effectively and creatively delivers the information in a logical sequence while staying on the topic and considering the audience. Interesting and vivid to hear and/or watch.</td>
<td>/5</td>
</tr>
<tr>
<td>Delivery / Presentation</td>
<td>Presentation is lacking in preparation and in practice of the delivery including voice, pacing and little or no use of pictures. Difficult to hear. (voice, posture, eye contact, gestures, pacing)</td>
<td>Presentation shows some preparation as well as some practice in the delivery including marginal use of voice, pacing and pictures. (voice, posture, eye contact, gestures, pacing)</td>
<td>Presentation shows satisfactory preparation as well as practice in delivery including use of voice and pacing. Some use of pictures, graphics, skits and real life media. (voice, posture, eye contact, gestures, pacing)</td>
<td>Presentation shows detailed preparation and practice in delivery including use of voice, pacing and the use of pictures, graphics, skits, real life media etc. Interesting and vivid. (voice, posture, eye contact, gestures, pacing)</td>
<td>/5</td>
</tr>
<tr>
<td>Creativity</td>
<td>No real original presentation ideas; does not engage audience.</td>
<td>Little original content; little engagement with audience. Mostly presented facts without engagement</td>
<td>Some original content; some taking advantage of audience’s attention and maintaining interest.</td>
<td>Original presentation; takes advantage and holds audience’s attention.</td>
<td>/5</td>
</tr>
<tr>
<td>Length</td>
<td>Within +/- 2 minutes of allotted time</td>
<td>Within +/- 1 minutes of allotted time</td>
<td>Within +/- 30 seconds of allotted time</td>
<td>Within the allotted time</td>
<td>/5</td>
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Total /30
SPH3U: The Flow of Energy

Energy is a mysterious quantity that allows us to do some wonderful things. If we can keep track of energy, we can make predictions about our world that we couldn’t easily do with forces.

A: The Flow of Energy

When objects interact, energy can flow between them. Often when energy is transferred it may change into or be stored in different forms, many of which you have heard of before: kinetic energy (energy of motion), gravitational potential energy (energy of height), chemical potential energy and so on. For this part of your investigation your group will need one pullback car.

1. **Reason.** We choose our system to be the car. Draw the car backwards across the table (don’t release it). During this process (the drawing back process), do you think energy is flowing into or out of the system? Explain.

A *system* is a set of objects whose properties we choose to keep track of. An *energy flow diagram* is an illustration of the energy that flows into or out of the system. Consider all the objects that are interacting. Inside the circle we list all of the objects that are in the system and the rest we list on the outside. We draw a line between each object representing each interaction. If we know which direction energy flows between the objects, add an arrow to the line.

2. **Represent.** Complete an energy flow diagram for the car while it is being pulled back at a steady speed.

3. **Explain.** Albert says, “I know I used energy to pull back the car, but I think that energy is just used up by my arm (I learned in biology that my cells burn the energy). It hasn’t flowed anywhere.” How can you prove to Albert that he is wrong? Explain.

4. **Represent.** Draw an energy flow diagram for the car after you release it, while the car is moving. Is energy flowing into or out of the system of the car during this process (the moving process)? What do you think is happening to the energy of the system?

Energy is never created or destroyed - it just flows into or out of a system, or transfers between one form and another within a system. This idea is called the *conservation of energy*.

5. **Represent.** Push the car forward along the table with your finger at a constant speed. Draw an energy flow diagram for the system of the car while it is moving at a constant speed. Describe the transfers of energy in this situation.
B: Energy Transfers
You need a marble for this next investigation.

1. **Observe and Describe.** Create an incline using a binder or notebook. Roll the marble up the incline and catch it when it comes to rest at the top. Describe what happens to the speed of the marble. What object was interacting with the marble to cause this to happen? What do you think happened to the kinetic energy of the marble?

2. **Represent and Explain.** Draw an energy flow diagram for the system of the marble plus the earth while the marble is traveling up the incline, after it has left your hand. Do you think the system (marble+earth) is gaining or losing energy? Explain.

An *energy bar chart* uses a bar graph to show the amount of energy stored in each mechanism (gravitational, kinetic, elastic, heat, etc.) at two different moments in time. Unless you know exact values, the exact height of the bars is not important as long as the comparisons are clear. The middle bar in the chart, \( W_{\text{ext}} \), represents the energy flow into or out of the system.

3. **Reason and Predict.** We will consider two events: (1) when the marble leaves your hand and (2) when it reaches the top of its trip up the incline. At those two moments in time we want to compare the energies in the system. Complete the bar chart for the energies of the system at moment 2. Explain your rationale.

4. **Predict.** Now we roll the marble up the incline and let it roll back down to its original position. Our third event will be when the marble returns to its original position. How much kinetic energy will it have at this moment? How does this quantity compare to the energies at moments 1 and 2? Draw this in the second bar chart.

5. **Test.** Observe your marble rolling up and down your binder. Do your observations confirm your prediction? Then test your prediction carefully using the track and motion sensor set up in your classroom.

6. **Reason.** Emmy lifts a book upwards at a constant speed. We note two events while the book is moving upwards. Complete an energy flow diagram and bar chart for the system of the book + earth.
SPH3U: Doing Work!

How do we transfer energy into or out of a system? Let’s find out!

A: The Energetic Cart

You need a dynamics cart for this part of the investigation.

1. **Describe and Represent.** We want to give the cart some kinetic energy. Describe how you can do this. Draw a force diagram and an energy flow diagram for the system of the cart during this process (while you are giving it kinetic energy.)

2. **Describe and Represent.** The cart is moving quickly and we want to remove kinetic energy from it. Describe how you can do this. Draw a force diagram and an energy flow diagram for the system of the cart during this process.

3. **Demonstrate.** Use the cart and show these two situations to your teacher. Move on while you wait.

Energy can be transferred into or out of a system by an external force. When this happens we say that the force does mechanical work (or simply just work) on the system. When energy flows out of the system due to the force, the system loses energy and we say that the force does negative work. When energy flows into the system, the system gains energy and we say the force does positive work. Energy is a scalar quantity and positive or negative work does not indicate any kind of direction, it only indicates a gain or loss.

B: Measuring Work

You need a wood block for this part of your investigation.

1. **Observe and Represent.** Place the wood block in the path of the cart. Give the cart a push, release it, and let it collide with the block. Draw a force diagram and an energy flow diagram for the system of the cart during the stopping process.

2. **Observe and Reason.** Try this a second time with the cart moving slower the before. Try again with it moving a bit faster. Describe what is different about the stopping process in each case. What could you measure about the stopping process to help keep track of this difference?

3. **Reason.** What quantities do you think will help determine the amount of work on the system during the stopping process? Explain. (Hint: there are two!)

4. **Reason.** There are other forces acting on the cart – a normal force and the force of gravity. During the stopping process, are these forces doing work on the system? Explain.
The work done by a force on a system ($W$) depends on three quantities: the size of the force ($F$), the displacement of the system ($\Delta d$) and the angle between the force vector and the displacement vector ($\theta$). These are related by the expression, $W = |F||\Delta d|\cos\theta$. The units of work may be expressed as N·m, but these are actually equivalent to the unit joules (J) for energy.

### B: Working the Angles

1. **Reason and Calculate.** A cart with a mass of 0.70 kg is initially at rest. Then it is pushed horizontally by a hand with a force of 10 N.
   - (a) Draw vector arrows for the force due to the hand and the displacement of the cart. Draw an energy flow diagram for the system of the cart.
   - (b) What is the angle between the two vectors? (We always compare angles by imagining drawing the vectors tail-to-tail.)
   - (c) After it moves a distance of 0.40 m, how much work (in joules) has been done by the force?
   - (d) Interpret the sign of the value for the work that you calculated. How much kinetic energy do you think the cart has now?

2. **Reason and Calculate.** The same cart is rolling along different a table and experiences a force of friction of 12 N. It rolls 0.35 m before stopping.
   - (a) Draw vector arrows for the force of friction and the displacement of the cart. Draw an energy flow diagram for the system of the cart.
   - (b) What is the angle between the two vectors? What is the work done by the friction force while bringing the block to rest?
   - (c) Interpret the sign of the value for the work that you calculated. How much kinetic energy do you think the cart originally had?

3. **Reason and Calculate.** Now you push on the cart for 0.50 m while it travels across the rough table. The friction force is still 12 N and you push horizontally with a force of 15 N.
   - (a) Draw energy flow and force diagrams for the system of the cart.
   - (b) Calculate the work done by each force acting on the system.
   - (c) What is the total work done on the system? How much kinetic energy did the system gain during this process?

---

The *net work* is the sum of all the work being done on the system. When the net work is positive, the system gains kinetic energy. When the net work is negative, the system loses kinetic energy. This idea is called the kinetic energy - net work theorem and is represented by the expression: $W_{\text{net}} = E_{k2} - E_{k1} = \Delta E_k$. Note that this is the same as finding the work done on the system by the net force vector: $W_{\text{net}} = |F_{\text{net}}||\Delta d|\cos\theta$. 

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The idea of work provides us with a handy way to measure the amount of energy transferred during some process. Now we need to figure out how to use work to find out how much energy transforms into kinetic or gravitational potential energy.

A: Work and Gravitational Potential Energy

1. **Represent.** Let’s go back to an earlier example. Emmy holds a book of mass $m$ in her hand and raises the book vertically at constant speed. Complete the diagrams and charts for the book-earth system.

2. **Describe.** During the process of lifting the book, describe the transformations of energy that occur.

3. **Explain and Calculate.** The amount of energy transformed into gravitational potential energy is equal to the amount of work done by the force of the hand on the book. Explain how to find the size of this upwards force. Carefully show how to create an expression for the work using the symbols $m$, $g$ and $y_1$ and $y_2$.

The **gravitational potential energy** ($E_g$) of an object of mass, $m$, located at a vertical position, $y$, above the vertical origin is given by the expression, $E_g = mgy$. The vertical origin is a vertical position that we choose to help us compare gravitational potential energies. At the origin the gravitational potential energy is equal to zero. So we always say that an object has a certain amount of $E_g$ relative to the vertical origin. The $E_g$ is not stored in either object, but rather in the interaction between them (the gravitational field). Note that the units for work and gravitational potential energy are N·m. By definition, 1 N·m = 1 J, or one joule of energy. In fundamental units, 1 J = 1 kg·m²/s². Remember: in order to get an answer in joules, you must use units of kg, m, and s in your calculations! Always use a positive value for $g$ in your calculations and choose upwards as positive – this is our energy-position sign convention.

B: Work and Kinetic Energy

Another example that we looked at earlier was our cart which was at rest and then speed up as we pushed on it with our hand.

1. **Explain.** We are going to create an expression to help us find the kinetic energy of our cart after we push on it. For each step you see in this process, identify each new equation used and explain what is being done.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Description</th>
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<tbody>
<tr>
<td>$E_{k2} - E_{k1} = W_{net}$</td>
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<tr>
<td>$E_{k2} = W_{net}$</td>
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<td>$E_{k2} =</td>
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</table>
The kinetic energy of an object is the energy stored in an object’s motion. The amount of kinetic energy can be found from the expression \( E_k = \frac{1}{2}mv^2 \). Where \( v \) is the instantaneous velocity of the object at the moment in time you are interested in. The value of the kinetic energy does not depend on the object’s direction of motion – energy is a scalar quantity. Remember, to get a result in joules, make sure you use units of kg and m/s in this equation.

C: The Ball Drop and Kinetic Energy

Next, you will drop a basket ball through a displacement of your choice (between 1 and 2 m) and examine the energy changes.

1. **Represent.** Draw a diagram of a ball falling and indicate two moments in time 1 and 2 at the start and end of its trip down (just before it hits!) Label the two vertical positions \( y_1 \) and \( y_2 \). Complete the energy-flow diagram and bar chart for the earth-ball system.

2. **Reason.** Create an equation that shows the relationship between the energies at moment 1 and 2. If you know a quantity is zero, it does not need to appear in your expression.

3. **Calculate.** Use the expression for kinetic energy and the expression for gravitational potential energy and substitute these into your equation from the previous question.

4. **Calculate.** What is the speed of the ball just before it reaches the ground?

5. **Test.** Use the motion detector set up by your teacher to measure the speed of the ball just before it hits the ground. Do the results support or refute your prediction?

Gravitational potential and kinetic energy are two examples of mechanical energy. When the total mechanical energy of a system remains the same we say that the mechanical energy is conserved. Mechanical energy will be conserved as long as there are no external forces acting on the system and no frictional forces.

6. **Reason.** Keeping in mind the experimental errors, was mechanical energy conserved during the drop of the ball? Explain.
SPH3U: Gravitational Potential Energy

We have had a brief introduction to energy stored due to an object’s position, that is, gravitational potential energy. Today we will explore this idea in depth.

A: The Ramp Race - Predictions

Your teacher has two tracks set up at the front of the class. One track has a steep incline and the other a more gradual incline. Both start at the same height and end at the same height. Friction is very small and can be neglected.

1. **Reason.** What energy transformations take place as the ball travels down the incline?

2. **Reason and Predict.** Two horizontal positions, 1 and 2, are indicated in the diagram. The two balls are released at the same time. Which ball do you think will reach position 2 first? Justify your prediction with energy arguments.

3. **Reason and Predict.** How will the speeds of the two balls compare when they reach position 2? Justify your prediction.

B: The Race!

1. **Observe.** Record your observations of the motion of the balls when they are released at position 1 at the same time.

2. **Observe.** Record your observations of the speeds of the balls when they reach position 2.

3. **Reason.** Albert says, “I don’t understand why ball B wins the race. They both end up traveling roughly the same distance and ball A accelerates for more time! It should be faster!” Based on your observations and understanding of energy, help Albert understand.

4. **Reason.** According to your observations, how do the kinetic energies of the two balls compare at position 2? Where did this energy come from?
5. **Reason.** The distance the balls travel along each incline is slightly different, but there is an important similarity. Compare the horizontal displacement of each ball along its incline (you may need to make measurements). Compare the vertical displacement of each ball along its incline. Illustrate this with vectors on the diagram on the previous page. Which displacement is the important one when determining the change in gravitational potential energy?

The amount of energy stored in, or returned from gravity **does not depend on the path** taken by the object. It only depends on the object’s change in vertical position (displacement). The property is called **path independence** – any path between the same vertical positions will give the same results. This is a result of the fact that gravity does no work on an object during the horizontal parts of the object’s motion.

**C: The Vertical Reference Position**

When making calculations involving gravitational potential energy, we must choose a vertical origin from which we measure the vertical position of the object. What effect does this choice have on the results of our calculations? Let’s see! In the following work, if there are any quantities you need to know, make a measurement of the equipment at the front of the room.

1. **Calculate.** In the diagram to the right, indicate the vertical origin at the bottom level of the track. What is the gravitational potential energy of the ball at positions 1 and 2?

2. **Calculate.** In the diagram to the right, indicate the vertical origin at the top level of the track. What is the gravitational potential energy of the ball at positions 1 and 2?

3. **Represent.** As the ball rolls down the track, there is a transfer of energy stored in gravity to energy stored in motion. Draw a vector representing the vertical displacement of the ball in each diagram. How do these two vectors compare?

4. **Calculate.** How does the change in gravitational potential energy, \( \Delta E_g \), compare according to the two diagrams?

5. **Reason.** According to our diagrams and choice of origin, how much kinetic energy will the ball gain? What does this imply about our choice of vertical origin?

**Only changes** in gravitational potential energy have a physical meaning. The exact value of the gravitational potential energy at one position **does not** have a physical meaning. That is why we can set any vertical position as the origin. The vertical displacement of the object does not depend on the choice of origin and therefore the **change** in gravitational potential energy does not depend on it either. So it is not a concern if an object has a **negative** gravitational potential energy.
A: The Behemoth
The newest rollercoaster at Canada’s Wonderland is called “The Behemoth” due to its 70.1 m tall starting hill. Assume the train is essentially at rest when it reaches the top of the first hill. We will compare the energy at two moments in time: 1 = at the top of the first hill and 2 = at ground level after the first hill.

1. **Represent.** Draw an energy bar chart and flow diagram for the earth-train system. Write down an equation that relates the energies of the system at moment 1 with moment 2.

![Energy Bar Chart and Flow Diagram]

Equation

2. **Calculate.** Use the energy equation to find the speed of the rollercoaster at moment 2 in km/h.

3. **Reason.** The official statistics from the ride’s website give the speed after the first drop as 125 km/h. What do you suppose accounts for the difference with our calculation? What happened to the energy?

4. **Reason.** Imagine we had an infrared thermometer (a device which we can point at things and get a temperature reading). Where could we point the thermometer in order to detect the heat energy lost during the trip down the hill?

When a force of friction does work on a system, energy can be transformed into heat, or *thermal energy* ($E_{th}$). This is another form of energy which we must account for in our understanding of energy. We do this by including the objects that heat up in our system. Thermal energy is not considered a form of mechanical energy since it is difficult to transform thermal energy into other forms of energy.

5. **Represent.** Draw a new energy storage bar graph and an energy flow diagram for the *earth-train-track* system. Write down a new energy conservation equation.

![New Energy Storage Bar Graph and Flow Diagram]
6. **Calculate.** Use the train mass, \( m_t = 2.7 \times 10^3 \text{ kg} \) to determine the amount of thermal energy at moment 2.

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### B: The York Mills Flyer

Rumour has it that a rollercoaster is going to be built in the York Mills courtyard. Plans leaked to the media show a likely design. The train starts from rest at moment 1. For all our calculations, we will assume that the force of friction is negligible.

1. **Solve.** Moment 2 occurs partway down the first hill. Complete the diagram and chart. Determine the rollercoaster’s speed at moment 2.

   ![](Diagram1.png)

   **Equation**

2. **Solve.** Moment 3 is the top of the loop-de-loop and is located 17 m above the ground. Complete the diagram and chart. Determine the rollercoaster’s speed at moment 3.

   ![](Diagram2.png)

   **Equation**

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The loop-de-loop involves some very complicated physics, the details of which are much beyond high school physics. Yet using energy techniques, we did not have to consider those complications at all! When the mechanical energy of a system is conserved, we can relate the total mechanical energy at one moment in time to that at any other moment without having to consider the intermediate motion – no matter how complex. **Wow!**
SPH3U: Power

Winning a race is all about transferring as much energy as possible in the least amount of time. The winner is the most powerful individual.

Power is defined as the ratio of the amount of work done, \( W \), to the time interval, \( \Delta t \), that it takes to do the work, giving: \( P = \frac{W}{\Delta t} \). The fundamental units for power are joules/seconds where 1 joule/second equals one watt (W).

A: The Stair Master

Let’s figure out your leg power while travelling up a flight of stairs.

1. **Reason.** Describe the energy changes that take place while you go up the stairs at a steady rate.

2. **Reason.** Explain what you would measure in order to determine the work you do while travelling up a set of stairs. Quickly sketch a diagram of this showing all the important quantities.

3. **Reason.** To calculate your power, you will need one other piece of information. Explain.

4. **Observe.** Gather the equipment you will need for your measurements. Travel up a flight of stairs at a quick pace (but don’t run, we don’t want you to fall!) Record your measurements on your diagram.

5. **Calculate.** Compute your leg power in watts (W) and horsepower (hp) where 1 hp = 746 W. How does this compare to your favourite car? (2011 Honda Civic DX = 140 hp)

B: Back to the Behemoth!

1. **Solve.** The trains on the Behemoth are raised from a starting position 10 m above ground at the loading platform to a height of 70.1 m at the top of the first hill in 60 s. The train (including passengers) has a mass of 2700 kg and is lifted at a steady speed by a motor. Ignoring frictional losses, how powerful should the motor be to accomplish this task? Complete the energy diagrams below for the earth-train system. In the energy equation, include a term, \( W_m \), for the work done by the motor.

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A: Oscillations and Amplitudes

You will need: a retort stand, a C-clamp, a test-tube clamp, a metal spring, a small object (~ 200 g), a ruler and a stopwatch. Hang the spring from the test-tube clamp on the retort stand. Secure the stand firmly using the C-clamp. Hang your object from the spring.

1. Give the object a small downwards pull and release it (gentle!). Describe the motion of the object. What is different about this motion compared to other motions we have studied in Gr. 11 physics?

We say that an object moving this way is vibrating or better, oscillating. Periodic or oscillatory motion is motion that repeats itself in a regular cycle or pattern. The displacement of the object is measured relative to its equilibrium position, which is the position the object would have if it was not in motion.

2. Measure how high above and below the equilibrium position the object oscillates (at least initially). How do these compare? With an ideal spring, these values would remain constant.

The largest displacement of the object from the equilibrium position is the amplitude of its oscillatory motion.

3. In the diagram to the right, draw three images of the spring and moving object at the indicated moments in time.

4. Draw a vector for each moment in time carefully showing the object’s displacement from the equilibrium position.

B: Cycles and Periods

A cycle is one complete oscillation, starting and ending at the same position after completing one whole motion. The time to complete one cycle is called the period (T).

1. A student wants to time the period of your object’s oscillation. He suggests, “I think we should start the timer when the object is at the equilibrium position, watch it go down to its lowest position, then back up to the equilibrium position and stop the timer.” Do you agree or disagree? Explain.

2. Measure the period of your object’s oscillations. Explain what a good technique would be to get a very reliable result.

3. On a graph of displacement vs. time, plot five points that correspond to (a) the highest position, (b) the equilibrium position, (c) the lowest position, (d) the equilibrium position, and finally back to (e) the highest position. How do you think these points will each be separated in time? Interpolate what you think the rest of the graph between these points might look like.
4. Use the motion detector set up at the front to plot the position-time graph for the oscillating object. Neatly sketch the result for a number of periods of time.

5. Choose two points on the graph at different positions. Use horizontal arrows to indicate one complete period of motion, starting from each of those points.

6. How many cycles does your object go through in one second of time? You can use your data from question B#2.

The frequency of periodic motion \((f)\) is the number of cycles of the motion per unit of time. This quantity is given by the expression: \(f = (\text{# of cycles}) / \text{time}\). The units of frequency are hertz (Hz) and mean “cycles per second”. Frequency and period are related by the expression: \(f = 1/\text{T}\) or \(\text{T} = 1/f\).

C: Phase

Consider the graph to the right showing the position vs. time for an oscillating object.

1. Draw the position of the object and spring according to the graph for each moment in time labeled in the diagram below.

2. Draw a vector beside each image of the object showing its instantaneous velocity. If it is zero, write a zero.

The phase of a particle in periodic motion indicates its state at one moment in time. The state of the oscillating particle can be completely described by its position and velocity. Phase is most often used for making comparisons. When two states are identical, they have equal phase or are in phase. Otherwise they are out of phase. When two states are half a cycle apart they have opposite phase. Note that the expression out of phase is commonly used to mean opposite phase. Be careful!

3. Find all the points which have the same phase as:
   B:
   C:
   D:

4. A student says, “I think points A and C have the same phase.” Do you agree or disagree? Explain.

5. Find all the points that have the opposite phase as:
   A:
   B:
   D:

6. Time for some exercise. Your group must demonstrate in phase, in opposite phase and just a bit out of phase. You may only use the people in your group – no equipment! Show your teacher.
SPH3U: Properties of the Pendulum

One of the most important examples of periodic motion is the pendulum. For this investigation you will need: a retort stand, a C-clamp, a test-tube clamp, string, a small mass (~ 200 g), a ruler and a stopwatch. Hang the mass from the string — leave extra string length so you can easily adjust it later. Secure the stand firmly using the C-clamp.

A: The Pendulum Cycle
1. Set your pendulum in motion. Explain why this is an example of periodic motion.

2. Draw the mass and string at three moments in time: (a) furthest displacement left, (b) equilibrium position, and (c) furthest displacement right. Draw a dashed vertical line for the equilibrium position of the mass and string.

3. Draw the path the mass takes starting from moment (a) in the diagram and completing one full cycle.

B: The Period of the Pendulum
What does the period of the pendulum’s cyclic motion depend on? Let’s find out! For all the investigations below, make sure your pendulum moves through small angles only (less than 30° from the equilibrium position).

1. How does the length of the pendulum affect the period? You will have to measure carefully, make sure your set-up is sturdy, and choose a very wide range of lengths to test.

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<th>Period (s)</th>
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2. State your conclusion.

3. Choose a different characteristic of the pendulum and determine whether it has an important effect on the period. Be sure that you only change that characteristic and not any others!

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<tr>
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<th>Period (s)</th>
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4. State your conclusion.
**SPH3U: Making Waves**

In our work so far, we have had only one particle to keep track of. Imagine now that we connect a whole series of particles together such that the movement of one particle affects the others around it. When we start a vibration in one particle, an effect will travel from one particle to the next – a wave has been created. The medium, modeled by our set of particles, is the material substance that the wave travels through, for example: water, air, strings, the earth and so many more!

**A: Particle Motion**

We will start our investigation by creating pulses in the Bell Labs Wave Machine. Be gentle with the machine – it can be easily damaged. Practice making a pulse which is simply a small, single bump above the equilibrium position.

1. Describe the motion of the pulse in the wave machine.

2. Watch one particle carefully as the pulse travels by it. Compare the direction of a particle’s motion (the rod) with the direction of the wave pulse’s motion. Draw a simple illustration of this.

In a transverse wave, the particles of the medium oscillate in a direction that is perpendicular to the direction of the wave motion.

3. Since no particles move horizontally what does? What is actually traveling back and forth in this medium? Make a guess and move on.

4. (as a class) What is a wave?

6. A “snapshot” of a transverse pulse travelling through a wave machine is shown in the diagram to the right. The pulse is traveling to the right at 50 cm/s. Three particles in the medium are marked with tape, A, B, and C. Each square in the diagram is 5.0 cm.
   (a) Between 0.0 s and 0.1 s, in what direction did each particle move?

   (b) How in what direction did the “peak” of the wave move? How far did it travel?

   (c) Draw the pulse and label the position of the tree particles at the time of 0.2 s.

   (d) How much time will it take for the complete pulse to pass through particle C?

   (e) What is the total distance that particle C will move?

   (f) How much time will it take for particle B to return to the rest position?

   (g) What is the average velocity of particle B between t = 0s and t = 0.1 s?

Adapted from *Activity-Based Tutorials*, by Wittmann, M., et al. John Wiley, 2004
B: Reflection of Pulses and Waves

You may have noticed that the pulses don’t just disappear when they reach the end of the medium - they reflect and travel back in the opposite direction.

1. Send a positive pulse (a pulse with positive displacements only = above the equilibrium position) through the medium and carefully observe the shape of the pulse before and after it reflects off the end of the medium. Sketch a diagram. Describe how the shapes compare.

2. Now have someone hold the end of the machine fixed (hold the last rod of the wave machine tightly with two hands). Send a positive pulse through the medium and carefully observe the shape of the pulse before and after it reflects off the end of the medium. Sketch a diagram. Describe how the shapes compare.

The end of a medium where the particles are free to move is called a free end. The end of a medium where particles are held in place is called a fixed end.

3. In which situation would you say the pulses or waves reflect in phase and in which situation would you say they reflect in opposite phase. Explain.

C: The Periodic Wave and Wave Pictures

Create a gentle, continuous, periodic wave in the wave machine. You may have to experiment a bit with the frequency of your vibrations so it “settles down” into a nice pattern – make sure you can see a whole wave.

A continuous or periodic wave has two parts that we call the crest and trough of the wave which correspond to the top of the positive and bottom of the negative displacements. The distance the wave travels in one cycle is equal to the distance between the two nearest points of equal phase. This distance is called the wavelength and is represented by the greek letter lambda (λ).

To measure such a distance, it is often convenient to choose two adjacent crests as the nearest points of equal phase.

1. Hold a ruler up to the wave machine and roughly measure its amplitude and wavelength (as if you could freeze the motion of the machine – or take a photo with your phone!)

Imagine taking a photograph of a periodic wave in the wave machine. From such a picture we can create a graph showing the displacement of the different particles in the medium. We will call this the position picture of a wave.
2. Sketch a position picture for your wave. Label your measurements and the axes of the graph.

3. Choose one particle in the medium and measure the period of its oscillations. Describe how you do this and show your results.

Imagine we track the displacement of one particle over time as a periodic wave travels through the medium. We can construct a graph showing the displacement of the particle as a function of time. We will call this the *time picture* of a wave.

4. Draw a time picture for this particle in your wave that completes 3 cycles. Label the amplitude measurement.

5. What does the interval between the two nearest points of equal phase represent in *this* picture? Explain.

6. Label the period \( T \) using a horizontal arrow starting from a crest, starting from a trough and starting from a point with a completely different phase.
SPH3U: Interference

What happens when two waves travel through the same medium and meet? Let’s find out!

A: When Waves Meet

1. What happens to the sound when two people are talking, each producing sound waves, and these waves arrive at the same point in space and overlap? Have you ever been in the middle of such a conversation? What do you hear?

2. What happens when waves or pulses meet? Briefly try sending the pulses shown in the chart below in the wave machine.

3. Watch the video and draw your observations of the spring when the pulses overlap and after they have overlapped.

<table>
<thead>
<tr>
<th>Before</th>
<th>Overlapping</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two crests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two crests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two Troughs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two Troughs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large crest and small trough</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal crest and trough</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Describe what happens when the waves overlap.

5. Do the waves bounce off one another or do they travel through one another?

When two ideal waves overlap, one does not in any way alter the travel of the other. While overlapping, the displacement of each particle in the medium is the sum of the two displacements it would have had from each wave independently. This is the principle of superposition which describes the combination of overlapping waves or wave interference. When a crest overlaps with a crest, a supercrest is produced. When a trough and a trough overlap, a supertrough is produced. If the result of two waves interfering is a greater displacement in the medium constructive interference has occurred. If the result is a smaller displacement, destructive interference has occurred.

6. Label each example in the “Overlapping” column of your chart as either constructive or destructive interference.
Let’s apply the principle of superposition to some sample waves and learn how to predict the resulting wave shapes. Each pulse moves with a speed of 100 cm/s. Each block represents 1 cm. A sample of the interference process is shown in the first column of diagrams.

1. Study the sample process. Draw an arrow on the first diagram showing the direction in which the pulses are travelling.

2. At what time do the pulses begin to interfere? At what time will they finish?

3. At \( t = 0.02 \) s, what type of interference occurs?

4. At \( t = 0.03 \) s, explain how to find the resulting wave shape.

5. The second column of diagrams is an example for you to try. How many boxes will each pulse travel between diagrams?

6. Complete the set of diagrams. Show the positions of the individual pulses with dashed lines and the resulting wave shape with a solid line.
A: Ideal Waves and Pulses

Real waves and pulses can be very complex. As a real wave or pulse travels or propagates through a medium it may gradually change.

1. (as a class) Use the wave machine to create a single pulse. Describe how the pulse changes while it travels back and forth through the medium.

Real waves lose energy as they travel causing their amplitude to decrease. The shape of a pulse also changes – often spreading out. We will always ignore these important and realistic effects and instead focus on studying ideal waves in a medium that does not lose energy or cause wave shapes to change.

B: The Speed of a Wave

There are three important characteristics of a pulse that we can easily control: the height (amplitude), the width (wavelength or period) and the shape (waveform – more about this later). We will make pulses with different heights and widths and see how these characteristics affect the speed of the wave.

1. (as a class) Make a pulse which will be your “standard” pulse. Get a feel for how quickly it travels back and forth through the medium.

2. We will vary the pulse in a number of different ways and make a rough judgement – does it appear to travel back and forth faster, slower or the same?

3. Draw a conclusion about the pulse or wave speeds in this medium.

The speed of a pulse or wave does not depend on the amplitude, shape or period (or frequency). It only depends on the physical properties of the medium, such as density, tension and variety of other factors.

C: Wave Speed in a Coiled Spring

We will use a coiled spring to study the motion of ideal wave pulses. If there is no space in the classroom, you will need to do this in the hallway. The spring must always remain in contact with the ground! Never let go of the spring while it is stretched! Be sure it does not get tangled up! Stretch the spring enough so you can clearly see a wave make a complete trip back and forth. You will need a measuring tape and stopwatch.

1. There is one characteristic of this medium (the spring) that we can easily change – the tension. Increase the tension and determine the wave speed. Use a medium spring scale.

2. Describe roughly how tension affects the wave speed.
D: Speed, Wavelength and Frequency

How is the speed of a wave related to its frequency and wavelength? Let’s think this through. The diagrams below show your hand which moves up and down with a fixed frequency as it generates a wave.

1. Study the motion of your hand in the diagram. What fraction of a cycle does your hand move through? Explain.

2. What do we call the time interval for the motion of your hand in this diagram?

3. What fraction of a wavelength do we see in each diagram? Label these lengths.

4. How far does a wave travel in the time of one period?

5. How could we find the actual wavelength of this wave if we knew the period (0.5 s) and the wave speed (4.7 m/s)?

Now you generate another wave, but the time taken by your hand has doubled. Nothing else about the situation has changed.

6. How will the frequency of your hand (and the wave) compare with the previous example?

7. How will the wave speed compare with the previous example?

8. How will the distance travelled by the wave during your one cycle of your hand’s motion compare with the previous example? Sketch this in the diagrams above. Label your diagrams like the previous example.

9. Describe how frequency affects the size of the wavelength. Be as precise as possible.

The universal wave equation, \( v = f \lambda \), relates the frequency and wavelength of a wave to the wave speed in a given medium. Note that a change in frequency affects the wavelength and vice versa, but do not affect the wave speed. The wave speed depends on the physical properties of the medium only.
SPH3U: Standing Waves

A: Interfering Waves

The diagram to the right shows two waves travelling in opposite directions in a spring.

The points A, B, and C are points of constant phase and travel with the wave. We will use these to help keep track of the wave.

1. Draw the superposition of these two waves when points B and C coincide. You should be able to do this without detailed math work. Borrow the transparencies of these waves to help visualize this. Label the places where constructive or destructive interference occurs.

2. Draw the superposition of these two waves when points A and C coincide.

B: Making Standing Waves

A standing wave is a wave pattern created by the interference of two continuous waves travelling in opposite directions in the same medium. It is called a standing wave because there are positions in the medium where the waves always interfere destructively and the displacement is zero (or almost zero). These locations are called nodes or minima. There are other positions where the waves always interfere constructively. These locations are called antinodes or maxima.

A convenient way to draw a standing wave is to show the actual medium at two moments in time, one half period apart. Use a dotted line for one moment and a solid line for the other.

1. Label the nodes and antinodes in the sample standing wave shown to the right.
C: Resonance and Standing Wave Patterns
You need a coiled spring, long measuring tape and a stopwatch.

1. Two people will generate a standing wave in the spring – one will drive it and the other holds their end fixed. A third person will measure the lengths and time the motion.

2. Create a standing wave with the lowest frequency you can manage. (More tension in the spring sometimes helps.) You’ve got the correct pattern if there is only one anti-node. Measure the length of the spring all the way up to the elbow of the person driving it. (That person’s arm is like the last bit of the spring). Measure the frequency of the standing wave. Complete the first row in the chart below.

<table>
<thead>
<tr>
<th>Oscillation Mode</th>
<th>Number of Anti-Nodes</th>
<th>Number of Nodes</th>
<th>Number of λ</th>
<th>λ (m)</th>
<th>f (Hz)</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.</td>
</tr>
</tbody>
</table>

3. Gradually increase the frequency driving the spring until you find the next standing wave pattern or oscillation mode. A new node should appear. Measure the frequency. Repeat this and complete the chart below.

4. Describe the patterns you see in each column when oscillation mode increases.

Number of antinodes:
Number of nodes:
Number of λ:
λ (m):
f (Hz):

5. Predict the standing wave pattern for the 5th mode. Sketch it below.
D: More Resonance

Let’s look at another example of resonance. Find the rubberband resonators at the front of the class. Keep one end fixed and stretch the other end out a bit. Pull on the free end with a periodic back-and-forth motion parallel to the elastic bands. Very gradually increase the frequency of your driving force while keeping the amplitude of your hand’s motion the same (challenging!).

1. Find the frequency at which resonance occurs. Explain how you can tell by the mass’s response.

2. Increase the frequency a bit past the resonant frequency. Describe what happens.

3. Speculate: How can the small motions of your finger drive such large motions in the rubber stopper at the resonant frequency?

E: Wine Glass Resonance

For this investigation you need one wine glass and some water. Keep the wine glass at the front table.

1. Wet the tip of your finger. Slowly and gently rub it around the rim of the glass until you hear a sound. The vibrations from your finger tip are causing the glass to vibrate at its resonant frequency.

2. What could you do to change the resonant frequency of the glass? (Hint – think of water) Make a prediction: How would the change you describe change the resonant frequency?

3. Test this out. Describe your results.
A: Longitudinal Waves

1. All of the waves we have studied so far have been transverse waves. Remind yourself: What is a transverse wave?

2. You need a slinky segment for the next part of this investigation. Attach a small piece of tape to a coil near the middle of the slinky. Stretch out the slinky with a fair amount of tension. Don’t over-stretch the slinky and damage it! Have someone pull the coils towards the hand of the person holding down an end. Release the coils and describe what you observe.

3. Illustrate with arrows how the piece of tape moves.

The particles in a longitudinal wave move parallel to the direction of the wave pulse. A longitudinal wave will cause some regions of the medium to become compressed, producing a compression where the density of the medium has increased. It will also cause some regions to become stretched out, producing a rarefaction where the density of the medium has decreased.

4. Label in the diagram above, the regions of compression or rarefaction.

B: The Sound Wave

A sound wave is any kind of longitudinal wave that travels through a medium. The sound waves we are most familiar are those that travel through air. A vibrating object causes a disturbance in the air particles around it and this disturbance travels outwards as a longitudinal wave.

When you put on your ear phones and crank up your mp3 player, a tiny membrane in the earphone vibrates back and forth creating a sound wave in the air near your ears. The diagram below shows the membrane and the air particles, both initially at rest.
How do the air particles appear to be distributed?

If we could watch a video of these particles, they would be travelling in random directions, bouncing off one another. This is the equilibrium state of the medium of air.

2. Now the membrane begins to vibrate. Describe what happens to the nearby air particles.

3. Then the membrane moves in the opposite direction. Describe what happens to the particles next.

The regions where the medium is compressed have a high air pressure and regions where the medium is rarefied have a low air pressure. Sound is a pressure wave. The diagrams above are good illustrations of how a sound wave is created by any vibrating source – not just your headphones!

4. Label the regions of high and low pressure in the diagrams above.

5. One air particle has been emphasized in black. Describe its overall motion. Trace its path on the bottom diagram. How does this motion agree with our understanding that sound is a longitudinal wave?

The regions of high and low pressure travel outwards from the vibrating energy source. If we could see this, it would look like a spherical shell expanding outwards from the source. The individual air particles do not travel any great distance – typically around a billionth of a metre (nm). They simply oscillate back and forth, more or less in place. It is the regions of high and low pressure that move outwards.

6. A student holds a tissue near the front of a speaker creating a loud sound. He claims that if he releases the tissue, it will “blow way” due to the sound waves travelling outwards. Do you agree or disagree? Use the model above to help explain why.
C: Representing Sound Waves

Drawing realistic sound waves or any type of longitudinal wave is very challenging, but luckily it can be simplified using a nice trick.

The first diagram to the right shows the air particles involved in a periodic sound wave. The diagram below it shows an identical wave, represented by slinky-type “coils”.

1. For both the air particle and slinky-coil diagrams, label the regions of high and low pressure with the letters “H” and “L”.

2. Plot on the graph below a data point for each high and low pressure region on the diagrams above.

3. The pressure will change smoothly from high to low. Complete the graph by sketching the parts in between the data points.

4. Is the interval between two adjacent crests the period or wavelength of the sound wave according to these diagrams? Explain how you can tell. Label these intervals with arrows in all three diagrams.

---

A sound wave can be represented on the computer using a microphone. When the high and low pressure regions reach the microphone, they push against the microphone surface. The electronics change the alternating pressure into an alternating voltage which the computer can read and display in a graph.

5. Use the microphone attached to the computer to verify your predicted graph for the sound created by a vibrating tuning fork. Be sure to strike the fork with a proper mallet or on something soft. Sketch what you observe and label the axes of the graph.

6. Does the diagram above show the period or the wavelength of the sound wave? Why?
SPH3U: The Propagation of Sound

A: Two Dimensional Sound Waves

A student is sitting in a classroom and her cell phone rings! During class! This scandalous event is shown in the diagram to the right. Four students are also shown in the diagram and they are labelled A, B, C, and D.

1. Which students can hear the sound from the cell phone? Explain. (There are no obstructions in the room.)

2. In what direction(s) does the sound wave from the phone travel?

3. Technically speaking, do all the students hear the ring at the same time, or different times? Explain.

If we could picture a sound wave, we would see a circular wave (well, actually a spherical wave) of compressions and rarefactions travelling outwards from the source. We can represent these regions of compression and rarefaction as circles. For convenience, we will choose to have the dark line represent the crest of the wave (compression).

4. A pure sound tone which has only one frequency will produce a regular, steady series of circles. Two examples are illustrated to the right.
   (a) Use arrows to label the crests (compressions) and troughs (rarefactions).
   (b) Which wave has the higher frequency? Explain how you can tell.

5. Draw a circle showing a sound wave that has just reached student C. Who has already heard this sound? Who has not heard it yet?

6. Normally we don’t notice the difference in times when each student hears the sound. Why?

7. Can you think of any situation where you have noticed a delay in the sound that you hear? Describe what is happening during one such experience.
B: The Speed of Sound

The speed of sound in air is given by the equation: \( v = 331 \text{ m/s} + 0.59 \left[ (\text{m/s})^\circ \text{C} \right] \times T \), where \( T \) is the air temperature in degrees Celsius. The warmer it is, the greater the speed of sound. Sound can travel through all sorts of materials – gases (like air), liquids (like water) and solids (like the earth). The speed of sound also depends roughly on the density of the medium the sound waves travel through. A higher density medium generally produces a greater speed of sound.

1. What is the speed of sound in this room right now? You may need to make a simple measurement.

2. Describe a situation in which you have heard sound waves travelling through
   (a) a liquid:

   (b) a solid:

3. What would happen in space? Imagine a foolish astronaut takes off his/her helmet and screams!
SPH3U: The Interference of Sound

A: Fiddly Dee, Dee-Dee, Two Speakers

1. Two speakers produce an identical pure tone (one steady frequency) at the same time. Make a prediction: How will the sound of two speakers compare with the sound of just one? Do you think everyone in the room would agree?

2. (as a class) Listen carefully and describe what you and your classmates notice.

Sound can interfere constructively or destructively just like we learned for waves in springs. Whether we hear the interference effects depends on many different factors. Sometimes it depends on our positions. Sometimes it depends on the time. In most cases it depends on the qualities of the sounds themselves.

B: Beats

For this investigation you will need one small elastic and two identical tuning forks, larger ones generally work better.

1. Strike one fork and touch it to your table. Explain what is happening.

2. Have two group members strike the forks and hold them both close beside one ear of the third group member or against the table. The sound should be very constant as it dies away slowly.

3. Tightly wrap the small elastic to the upper tine of the tuning fork. Strike both and quickly hold them by the third member’s ear or against the table. Describe how the sound is different as it dies away. If there is no obvious difference, wrap a second small elastic band on the same tine and try again. If you still don’t notice the difference, ask for help.

4. Adding the elastic has changed the frequency of the tuning fork very slightly. Do you think the frequency of the fork with the elastic has increased or decreased? Explain.

Two sound waves with slightly different frequencies interfere and produce beats. Our ears perceive this as a throbbing sound. The frequency of the throbbing sound is called the beat frequency which can be found by taking the absolute value of the difference in the original sound wave frequencies: \( f_b = |f_2 - f_1| \). Reminder: the absolute value signs always make \( f_b \) a positive value. This throbbing sound is often heard when musical instruments are slightly out of tune.

5. Measure as best you can the beat frequency of the two tuning forks. Use this to find the altered frequency of the fork with the elastic.

C: The Characteristics of a Musical Sound

In the graph to the right is a very simple sound wave that we will use for our comparisons. This sound wave is an idealized one, but is very close to that produced by a tuning fork. Answer questions 1-3 below and then we will check your predictions using the computer oscilloscope.
1. We now strike the same tuning fork harder so the sound it makes is **louder** (the only difference). What characteristic of the wave would change? Sketch your prediction to the right. Provide a brief rationale.

2. Next we strike a smaller tuning fork that has a higher **pitch**. What characteristic of the wave would change? Sketch your prediction to the right. Provide a brief rationale.

3. Finally, we choose a violin and bow the violin such that it produces a sound with the same pitch and loudness as the original. Here the sound has a different quality or **timbre**. What characteristic of the wave do you think would change? This is a hard one – just make a guess!

4. Define the following terms based on your observations of the computer results.
   
   (a) loudness:
   
   (b) pitch:
   
   (c) timbre:

   When a real object like the string on a violin or the air in a flute vibrates, it can vibrate in many modes **at the same time**. These modes or harmonics **interfere** according to the superposition principle and create sound waves with more complex shapes or **waveforms**. The particular combination of harmonics is what gives a musical instrument or a person’s voice its distinctiveness. A **pure tone** has very few harmonics and a **complex tone** has many.

5. Next, we will blow on the microphone which will create **white noise**. Describe (don’t draw yet) what you think the graph for white noise might look like.

6. In a previous investigation, we explored the phenomena of beats. Describe (don’t draw yet) what you think the graph might look like.

7. Here is an example of two harmonics sounding at the same time and interfering, creating a new timbre. Use the superposition principle to find the shape of the graph when they interfere!
SPH3U: The Vibrating String

One of the most ancient topics in physics is the study of the vibration of strings. The patterns of vibrating strings have fascinated people from Pythagoras all the way to the present day where you may have heard of the theory of subatomic particles known as “String Theory” from the TV show, The Big Bang Theory.

A: String Theory

For this investigation you will build your own sonometer – a device to help study the vibration of strings. To do this you will need a tissue box, two pens or pencils, and a couple of elastics that can easily fit around the box. Assemble your sonometer according to the diagram. The elastic vibrates in the space between the two pencils. The elastics push on the box periodically which begins to resonate with the elastic. This amplifies the sound.

1. Slide one of the pencils closer to the one. Describe what happens to the pitch of the sound of the string.

2. When the string is one half its original length, describe how the pitch of the original and new sounds compare. If you have a hard time describing, see if there is a violin, guitar, erhu, or zheng player in your group or a nearby one.

3. Set the pencils far apart. Pull on the elastic along the side of the box. What characteristic of the elastic are you changing? Describe what happens to the pitch of the sound?

4. Choose a different elastic and remove the current one on the box. Place the two side by side and describe how they are different.

5. Predict how their pitches will compare.

6. Put both on to the box side by side. Do the sounds agree with your prediction? Offer a reason why or why not.

7. What conclusions can you make about the relationship between frequency and length and between frequency and tension?
B: Frequency and Length – A Violin Lesson

The shorter the vibrating string, the higher the frequency. For a given string and tension we have the relationship: 
\[ \frac{f_2}{f_1} = \frac{L_1}{L_2}, \]
where \( f_1 \) and \( L_1 \) are the original frequency and length of the string and \( f_2 \) and \( L_2 \) are the new frequency and length. The ratio between two frequencies \( f_2 / f_1 \) defines a musical interval.

The standard violin has its “A” string tuned to the pitch known as A-440, meaning a frequency of 440 Hz. Its four strings vibrate between the nut and the bridge. By placing your fingers on the fingerboard you change the length and frequency of the string.

1. The chart below shows the ratios for some typical musical intervals. According to the ratios, how does the frequency of a note a perfect fifth higher compare with the lower note?

2. Explain how the length of the string should be changed to produce the note ‘E’.

3. Calculate the frequency for each new pitch. Always use A-440 as \( f_1 \). Measure the length of the string on the diagram. Calculate the new lengths of the string for each note. Carefully label the position on the image of the violin where the player would place her fingers to produce the desired note. Show one sample calculation below for the frequency and finger location of the musical note ‘E’.

<table>
<thead>
<tr>
<th>Musical Interval</th>
<th>( f_2 / f_1 )</th>
<th>Musical Note</th>
<th>( f_2 )</th>
<th>( L_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect Unison</td>
<td>1 / 1</td>
<td>A</td>
<td>440 Hz</td>
<td>=</td>
</tr>
<tr>
<td>Major Second</td>
<td>9 / 8</td>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major Third</td>
<td>5 / 4</td>
<td>C#</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfect Fourth</td>
<td>4 / 3</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfect Fifth</td>
<td>3 / 2</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major Sixth</td>
<td>5 / 3</td>
<td>F#</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major Seventh</td>
<td>15 / 8</td>
<td>G#</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfect Octave</td>
<td>2 / 1</td>
<td>A’</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: **you do not** need to memorize any intervals for a test or exam!

Sample calculation:
You may, or may not, be an accomplished bathroom shower singer. If you are, you are likely well acquainted with resonance in the shower. You might have noticed that while singing, if you find the right pitch, the loudness of your voice increases significantly and surprisingly. Something about the sound wave you created matched the volume of air you are in and resonance was the result!

A: Finding a Resonant Length

In this investigation, instead of changing the sound to match the volume of air, you will change the size of the volume of air to match the sound. You will need a large graduated cylinder, a long plastic tube, a metre stick and a tuning fork (512 Hz are best).

1. Fill the cylinder with water until about 5 cm from the top. Have one group member in charge of making sure it does not tip over during the experiment. Place the hollow tube inside the cylinder.

2. Strike and hold the tuning fork just above the tube. Slowly raise the tube until you hear the first resonance – the sound will suddenly become louder. Keep striking the fork so it doesn’t become too soft.

3. When you have found the resonant length, move the tuning fork close to and away from the opening of the tube. Explain why this situation is an example of resonance.

This is an example of resonance in a closed column of air. A closed air column has one end closed and other end open. When resonance occurs in the air column, a standing wave is created. Because this is a closed column of air, the standing wave always has a node at the closed end and an antinode at the open end. At the closed end, the air particles rub against the surface and cannot move freely which creates a node. This is similar to the reflection of a wave from a fixed end. At the open end they have the most freedom to move.

4. Make sure you have found the shortest length of tube that produces a resonance. This is the first resonant length. Use a ruler to measure the length of air column. Label this on the diagram to the right.

5. Based on your measurement and the diagram, explain how you can determine the wavelength of sound wave. Hint: What fraction of a wavelength or cycle is in the air column?

6. Continue the experiment by looking for the second resonant length. This is the next standing wave pattern that this frequency can produce. Measure the length of this air column and label it on the diagram.

7. How many nodes and antinodes will be in this pattern? Sketch the standing wave in the diagram below. What fraction of a wavelength is in this air column?
The successive resonant lengths of an air column for a fixed frequency have an additional node and are half a wavelength longer. This is true for all types of air columns.

**B: Finding a Resonant Frequency**

For this investigation you will use a large cardboard tube and the computer signal generator. The cardboard tube has two open ends. This time, we won’t change the length of the air column. Instead, we will change the frequency of the sound and find the frequencies that create a standing wave in the air column (like in our bathroom!)

An open air column has two ends open. When resonance occurs and a standing wave is created in the air column, there is an antinode at each of the open ends. The set of frequencies that produce a standing wave in a medium of fixed length are called the overtones or harmonics. As an example, the flute consists of an open air column and moving up to the next harmonic is called overblowing.

1. The simplest standing wave pattern that can form in an open air column has one node in the centre and an antinode at each end. Sketch what you think this standing wave will look like.

2. Measure the length of the tube. What fraction of a wavelength is in the air column? Make a calculation: What is the frequency of the first harmonic?

3. The second harmonic will have an additional node in the standing wave pattern. Sketch what you think this standing wave will look like.

4. Will the frequency of the second harmonic be higher or lower than the first? Explain.

5. Make a calculation and determine the frequency of the second harmonic.

6. Can you quickly predict a few more harmonics? Try!

7. Test your predictions using the cardboard tube and computer signal generator. How close were you?
1. A deep, dark well with vertical sides and water at the bottom resonates at 7.00 Hz and at no lower frequency. (The air-filled portion of the well acts as a tube with one end closed and one open end.) The air in the well is cool, with a temperature of 14°C. How far down in the well is the water surface?

2. The A string of a violin is a little too tightly stretched. Four beats per second are heard when the string is sounded with an A-440 tuning fork. What is the period of the violin string oscillation?

3. You are at a large outdoor concert, seated 300 m from the speaker system. It is a cool summer evening with a temperature of 18°C. The concert is broadcast live via satellite (at the speed of light, 3.0 x 10⁸ m/s). Consider a listener 5000 km away from the broadcast. Who hears the music first, you or the listener and by what time difference?

4. A column of soldiers, marching at 120 paces per minute, keep in step with the beat of a drummer at the head of the column. It is observed that the soldiers in the rear end of the column are striding forward with the left foot when the drummer is advancing with the right. It is a cold day with a temperature of 0°C. How long is the column of soldiers?

5. A 30 cm violin string vibrates in its fundamental mode and produces a concert A pitch of 440 Hz. What is the speed of the wave in the violin string?

6. John times a pulse that travels along a 10.0 m wire in 0.85 s. What are the three lowest frequencies for standing waves in this wire?

7. A clarinet behaves as a closed column of air with the open end at the bell and the closed end at the reed. Claudia blows very gently – just enough to play a low A with a frequency of 220 Hz. She then blows harder (overblows) using the same fingering and produces the next higher note (the next mode). What is the frequency of the higher note? Can you determine its pitch? (Consult the violin page!)

8. A large wood block of a xylophone vibrates with a standing wave pattern that is similar to an open air column (an antinode at each end and two nodes in between). The block is mounted on the steel frame at the nodes. The hard wood used for the blocks has a wave speed of 3600 m/s. How far apart are the two nodes for an E (2640 Hz)?

9. A skyscraper will often oscillate due to the wind blowing against it (gusting). It vibrates like a closed air column in the fundamental mode (node at bottom, antinode at the top). Engineers calculate that transverse waves will travel through the structure at a speed of 43 m/s. For a wind that typically gusts with a period of 12.0 s, what height of building will vibrate the most?

10. A building will often vibrate in a standing wave during an earthquake. It vibrates like an open air column in the fundamental mode (antinode at the top and bottom). Engineers calculate that transverse waves will travel through the structure at a speed of 37 m/s. What height of building would be the most dangerous during an earthquake with a frequency of 2 Hz?

11. A tuning fork of unknown frequency makes three beats per second with a standard fork of frequency 384 Hz. The beat frequency decreases when a small piece of wax is put on a prong of the first fork. What is the frequency of this fork?

Answers: 1) 12.1 m, 2) 0.002 s, 3) 0.86 s, 4) 231 m, 5) 264 m/s, 6) 0.59 Hz, 1.18 Hz, 1.76 Hz, 7) 660 Hz, 8) 0.68 m, 9) 130 m, 10) 9.25 m, 11) 387 Hz
SPH3U: Build a Musical Instrument!

Hand in this sheet with your instrument and poster

| Group Members: ___________________________ |
| Instrument Name: ___________________________ |
| Proposal due date: ____________________   | Instrument and poster due date: ______________________ |

Your task is to design and build a musical instrument, and then present it to the class.

**Instrument Specifications:**
- The instrument must be capable of playing a one octave (8 note) major scale.
- You may not use parts for actual instruments except for strings
- It cannot be a rubber band tissue box or set of glasses (glass harmonica)!
- **You may not use the school shop for this project!** Please speak to your teacher if you need help with any materials.

**Presentation:**
- Give a two-minute maximum description of the instrument – how it works, how you built it
- Perform a major scale and simple song
- Each group member must participate in the presentation

**Poster:**
- Use diagrams or photos of your actual instrument to explain how it works and how it creates the different notes
- Physics terminology is important!
- Size = 8½ x 11 page

**Proposal (5 marks)**
Handed-in on time, diagram of instrument design, time-line for group work, list of who does what

**Poster (10 marks)**

| Explanation (5 marks): physics concepts used and well explained, clear organization, application to instrument clearly explained |
| Grammar, Spelling (2 marks): correct English usage |
| Appearance (3 marks): visually pleasing, clear layout and organization, use of headings, diagrams |

**Instrument (25 marks)**

| Design and Construction (10 marks): construction neatly done, sturdy workmanship, good use of materials, interesting or creative ideas |
| Musical Capabilities (10 marks): has 8 note major scale, in tune, easy to play |
| Visual Appearance (5 marks): attractively made or decorated |

**Total Mark: /40**
SPH3U: The Flow of Electricity

How do electric circuits work? What happens when we flick on the light switch at home? In this investigation, we begin to explore how electrical circuits work.

A: How Many Ways Can You Light a Bulb?
You will need a battery, a light bulb and a single wire.

1. In the chart below, connect the three items together in a variety of ways. Draw a sketch (not a circuit diagram!) of two arrangements that cause the bulb to light on the left and two arrangements that don’t on the right.

<table>
<thead>
<tr>
<th>Bulb lights</th>
<th>Bulb doesn’t light</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. According to your examples, what conditions are necessary for the bulb to light? How are those conditions not satisfied in the arrangements that don’t light up?

A closed circuit is one in which electricity can flow. An open circuit does not allow current to flow.

3. Describe how a circuit must be built in order to create a closed electric circuit. Label the circuits above as open or closed.

B: Investigating Current Flow

1. Briefly connect the bare wire from one end of the battery to the other. (Don’t leave it attached too long or you will ruin the battery!) Describe how the wire and the battery feel.

2. Feel the wire in a few different places. What do you think is happening at one place compared to the others?

The flow of electricity is called the electron current, or just simply, the current. We picture this as the movement of negative charges (the electrons) through the parts of an electric circuit.

Adapted from Workshop Physics Activity Guide: 4 – Electricity and Magnetism, Laws, John Wiley & Sons, 2004
3. Based on your observations of the circuit in question B #2, in which parts do you think current flows?

C: Measuring Current Flow

An ammeter is a tool that measures the size and direction of the current that flows through it. Electric current is measured in units of amperes or amps (A). Remember that current is the flow of electric charge. The unit for electric charge is the coulomb (C) which represents a very large number of individual electrons (just like a dozen represents a large number of eggs!) One amp of current is defined as one coulomb of charge flowing past a point every second. This can be shown with the equation: \( I = \frac{Q}{\Delta t} \), where \( I \) is the current, \( Q \) is the number of electrons measured in coulombs and \( \Delta t \) is the interval of time during which the charge flows.

To measure the current travelling through one part of a circuit, simply “insert” the ammeter into that location in the circuit. Set up the circuit as shown in the diagram to the right.

1. What is the value of the current in amperes? Is it positive or negative?

2. Reverse the leads going into and out of the ammeter. Explain what happened to the meter reading.

D: A Model for Current Flow

1. Examine the four diagrams below and the explanations provided with each. Explain which you think provides the best model for the flow of the electric current.
2. Your goal is to make some measurements which will clearly indicate which model is correct. Decide what circuit you should build to test the models. Draw a picture of the circuit and show where you will place the ammeter in order to make the necessary readings. Record your measurements (including the sign) along side your diagram.

3. Explain how your measurements eliminate three of the models and confirm the fourth. Call your teacher over to explain your results.

4. **Apply.** Does the location of the open switch in the circuit change whether or not the bulb lights up? Use your new theory of current flow to help explain.
**A: Drawing Electric Circuit Diagrams**

A circuit diagram is a simplified drawing of an electric circuit. Instead of drawing pictures of the parts in a circuit, we use simple symbols like the ones shown below. Any wires are drawn using straight lines and right angle corners. It is important to remember that a circuit diagram shows the electrical connections of a circuit, not its physical layout.

The circuit you built in part C of the previous investigation has a circuit diagram that is shown below.

1. Draw the circuit diagram (do it neatly with a ruler!) for the circuits shown below.

**B: Voltage Rise and Drop**

A battery is a device that increases the potential energy of electric charges which can then flow through a circuit. A charge moving through a battery will go from a low potential energy to a high potential energy. The electric potential difference (\(\Delta V\)) is the gain in energy by each unit of electric charge. The unit for potential difference is volts (V) and potential difference is often referred to as voltage. A voltmeter measures the electric potential difference between two parts of a circuit.

1. Construct a circuit with one bulb and a switch. Close the switch while you make your measurements, but don’t leave it closed or you will ruin the battery! Connect both the positive and negative leads of the voltmeter to the same point in the circuit. Draw the voltmeter symbol and wire leads attached to the circuit to show each reading. Record the voltage reading (don’t worry about the positive or negative signs yet). Try this again at a different point in the circuit.

2. What do you conclude about the difference in voltage when the leads are connected to the same point (i.e. to each other)? What does this imply about the difference in potential energy at the ends of the leads?
3. Measure the voltage across the battery. Draw the voltmeter in the diagram and show where the leads connect. Record your measurement on the diagram.

4. Measure the voltage across the bulb. Draw the voltmeter in the diagram and show where the leads connect. Record your measurement on the diagram.

A source of energy like a battery causes the electric potential energy of the charges to increase. We call such an increase in voltage a voltage rise. An element of a circuit like the light bulb is called a load and loads cause the electric potential energy of the charges to decrease. Such a decrease is called a voltage drop. A potential difference of 1 volt is defined as a change in potential energy of 1 joule for each coulomb of charge, or $1\text{ V} = 1\text{ J/C}$. This is represented by the equation: $\Delta V = \Delta E/Q$.

5. Suppose you measured a voltage rise of 3V when the voltmeter was connected across the battery. Let’s understand what this reading tells us about the charges. Describe how the energy of each unit of charge (one coulomb) changes when travelling through the battery. (For example, $Q = 1\text{ C}$, $\Delta V = 3\text{ V}$)

6. Is there a voltage rise or drop across a single wire? What does this tell us about the gain or loss of energy as charges travel through the wire? Show where you connected the voltmeter leads on the diagram.

We will record all our voltage values as positive quantities for both rises and drops. This is our voltage sign convention. From our understanding of the voltage measurement, we know whether it is a rise or drop (if it’s a source or a load) so we can always decide if energy was gained or lost. Our future work will be simpler using only positive voltages. We will ignore any negative signs appearing on the voltmeter.

7. Label each element of the circuit in Q#6 as a voltage “rise” or “drop” along with the voltage value.

8. Imagine a charge making a complete trip through your circuit. What happens to the energy of that charge during the complete trip?

9. Devise a rule that describes the total change in voltage in a complete circuit – use the terms rise and drop. Don’t use any math.

**Preliminary Rule for Voltage:**

10. Use your new rule to predict the voltage drop across the bulb in the previous circuit if we double the voltage rise of the cell. Test your prediction.
A: Batteries in Series and a Single Bulb

1. Two 1.5 V cells are connected in series. What do you predict the total voltage across the two batteries will be?

2. Build this circuit. Measure the current and voltage as shown. Record the result beside the meters in the diagram.

3. What do you think happens to the energy of a charge as it travels through the two cells?

B: The Two Bulb Circuit - Predictions

Don’t build this next circuit yet! Let’s make a few quick predictions about the two-bulb circuit shown to the right. Don’t spend too long on your predictions.

1. How do you think the total voltage across the two cells will compare to your previous circuit with only one bulb? Explain.

2. What do you think will happen to the brightness of the first bulb when you add a second bulb to the circuit? Will it get brighter? Dimmer? Remain the same? Explain.

3. What will happen to the current drawn from the battery? Will it remain the same, decrease or increase? Explain.

C: The Two Bulb Series Circuit

Set up a two-bulb circuit with identical bulbs connected one after the other as shown. Bulbs connected in this way are said to be connected in series.

1. Measure the voltage across the cells when the switch is closed. Add a voltmeter to your circuit diagram showing how you connected it to make this measurement. Record your results beside the meter.

2. Did the voltage across the battery change significantly? Did the addition of the second bulb change the potential difference across the cells?

3. Did the first bulb dim when you added the second bulb to the circuit? What happens to the current drawn from the battery? Add an ammeter to your circuit diagram showing how you connected it to make this measurement.
4. Is the cell a source of constant current? Does the amount of current flowing through the cells depend on the other elements connected in the circuit? Why or why not?

An ideal battery is a source of a constant voltage, no matter what circuit is connected to it. Real batteries are to a good approximation a source of constant voltage.

We may think of a bulb as presenting an obstacle, or resistance, to the current in the circuit.

5. Would adding more bulbs in series cause the total obstacle to the flow, or total resistance, to increase, decrease, or stay the same as before?

6. Devise a rule for the total resistance of elements connected in series. Don’t use any math.

   **Preliminary Rule for Total Resistance of Elements in Series:**

7. Describe how the current through the battery would change (increase, decrease or remain the same) if the number of bulbs connected in series were increased or decreased. Use the term total resistance in your explanation.

D: Expanding Our Model for Current Flow

What is happening inside a circuit to produce the results we have found from part C of our investigation? What can we picture charges doing when they flow? Consider the illustration below and answer the following questions. Note that due to the pegs on the incline, the balls end up rolling down at a fairly constant average speed (from all the stopping and starting due to the collisions).

1. What would happen to the ball current (the rate of ball flow) if twice as many pegs were placed in the path of the balls on the incline?

2.

What would happen to the ball current if the ramp was raised to twice the height (a steeper angle), so they have twice the gravitational energy when they start to fall?

3. Label on the diagram which elements of the model correspond to elements of a circuit consisting of battery and bulbs. Use the labels from the following lists.
   Model: average speed of balls, number of pegs encountered, person raising balls, height of the ramp
   Electrical: number of bulbs, battery action, current, voltage of battery

4. What ultimately happens to the gravitational potential energy given to the balls by the person? What do you think might happen to the electrical potential energy of an electron as it passes through a bulb?

5. Use this model to explain why electric current isn’t used up when it flows through a bulb.

6. What would happen to the “ball” current if the velocity down the incline doubles? What can you do to the ramp to increase this velocity?

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**E: Potential Difference**

Let’s return to the circuit we were using earlier. With one change: double the resistance of one of the bulbs (right click).

1. Measure the potential difference across each element in the circuit. Record this beside each circuit element. Treat the two cells as one.

2. Consider the voltage rule you devised from question B#9 of the previous investigation. Does it still work in this situation? Or do you need to modify it? Explain.

3. Revise or rewrite your voltage rule. Don’t use any math.

<table>
<thead>
<tr>
<th>Preliminary Rule for Voltage in a Loop:</th>
</tr>
</thead>
</table>

3. Use this rule to explain what is happening to the energy of a single charge as it travels through the circuit above.
SPH3U: Bulbs in Parallel

A: The Two Bulb Parallel Circuit - Predictions

Don’t build the circuit yet! There is a second way to connect two bulbs in a circuit. Instead of connecting one after the other (in series), they are connected side-by-side, or in parallel, as shown in the diagram to the right.

1. Is it possible for a charge to travel from the source, to bulb A and back to the source without passing through bulb B? Colour this path on the diagram.

2. Is it possible for a charge to travel from the source, to bulb B and back to the source without passing through bulb A? Draw this path on the diagram with a different colour.

These paths correspond to different complete loops in the circuit through which current can flow. A particular charge only ever travels through one loop in a circuit.

To help us make comparisons, we will modify the circuit by placing a switch in front of the second bulb. Make your predictions below quickly and move on.

3. When the switch is open (like in the diagram) bulb B will not light up. Explain why. When this happens, our circuit is just like the single bulb circuit from part A of this investigation.

4. We will call the brightness of the bulb before the switch is closed A₁. After the switch is closed we will call them A₂ and B₂. Which of these three do you predict will be brightest? Dimmest? Will any be the same? Rank them and explain.

B: The Two Bulb Parallel Circuit - Measurements

1. Build the circuit, open and close the switch and describe the relative brightness of the bulbs before and after. Only mention large differences in brightness. Don’t leave the battery connected for extended periods of time. Disconnect it after you make your observations.

2. Did closing the switch and connecting bulb B in parallel with bulb A significantly affect the current through bulb A? How do you know?

3. Connect an ammeter into the circuit path for bulb A as shown in the diagram. Record the measurements for the current flowing through bulb A and B when the switch is open and closed.
   - Bulb A current with switch open: ______________
   - Bulb B current with switch open: ______________
   - Bulb A current with switch closed: ______________
   - Bulb B current with switch closed: ______________
C: The Battery

1. Predict: How does closing the switch affect the current flowing through the battery (that is, through point D – see below)? Explain your reasons.

2. Predict: How do you think closing the switch will affect the voltage across the battery? Explain.

3. Test your prediction by inserting an ammeter into the circuit at point D. Record your measurements below.
   - Battery current with switch open: ____________ amps
   - Battery current with switch closed: ____________ amps

4. Test your prediction by placing a voltmeter across the battery. Record your measurements below.
   - Battery voltage with switch open: ____________ volts
   - Battery voltage with switch closed: ____________ volts

5. Based on today’s observations, define a preliminary rule for describing what happens to the current at a junction point (a branching point in a circuit). Don’t use any math.

   **Preliminary Rule for Current at a Junction:**

D: Elements in Parallel Circuits

1. Does the addition of more bulbs in parallel increase, decrease or not change the total resistance of the circuit connected to the battery? Use your current measurements to help decide.

2. Devise a preliminary rule for the total resistance of elements connected in parallel. Don’t use any math.

   **Preliminary Rule for the Total Resistance of Elements in Parallel:**

3. Does the total resistance of the circuit depend only on the number of bulbs in a circuit, or does the arrangement of the bulbs matter?
1. Rank the following circuits in order by current through the battery. Explain your reasoning.

2. Consider the following dispute between two students. Which student is correct?

Student 1: “Circuit 1 and circuit 2 are different circuits. In circuit 2 the bulbs are the same distance from the battery, but in circuit 1 one bulb is closer to the battery. So the brightness of the bulbs could be different in the two circuits.”

Student 2: “Circuit diagrams don’t show physical layout, only electrical connections. In each diagram, the electrical connections are the same. Each bulb has one terminal directly connected to one terminal of the battery and the other terminal of each bulb is directly connected to the other terminal of the battery. So the brightness of the bulbs will be the same in each circuit. Both diagrams represent the same circuit.”

3. Consider the circuit diagram to the right. What would happen to the brightness of the other bulbs in the circuit if one of the bulbs were to burn out (so that no current could flow through it)? Explain your reasoning.

4. Identical bulbs are connected to identical batteries in the various circuits below. Rank all the bulbs (A-H) in order of brightness. If two bulbs have the same brightness, state that explicitly. Explain your reasoning.
SPH3U: A Complex Circuit

A: A Complex Circuit - Predictions

The circuit to the right shows a more complicated combination of three identical bulbs. Use a 3 V battery for this investigation (or two 1.5 V in series). Use your preliminary rules to help make your predictions below. Don’t spend too much time – predict and move on.

1. When the switch is closed, are bulbs B and C in series or parallel with one another? Explain.

2. When the switch is closed, is bulb A in series with B alone, with C alone or with a parallel combination of B and C?

3. When the switch is closed, is the resistance of the combination of B and C larger than, smaller than, or the same as B alone? Explain.

4. When the switch is closed, will the total resistance of all the bulbs be greater than, less than or the same as when the switch is open? Explain.

5. Will the current through bulb A change when the switch is changed from open to closed? What will happen to its brightness?

6. When the switch is closed, predict the relative brightness of the three bulbs.

B: A Complex Circuit – Observations

Build the circuit according to the diagram above.

1. Rank the brightness of the bulbs when the switch is both open and when it is closed.

2. Describe any differences between your predictions and observations. There may be a few!

3. Based on your observations of the brightness, what happens to the current through bulb A when bulb C is added in parallel with bulb B?

4. What happened to the current through the battery? What do you conclude happens to the total resistance in the circuit? Does this agree with your two rules for total resistance? Explain.

Adapted from Tutorials in Introductory Physics, McDermott, Prentice Hall, 2002
C: A Complex Circuit - Measurements

1. Complete the chart showing measurements of the currents through the bulbs. Insert an ammeter at point D, E and F to make these measurements.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Switch open</th>
<th>Switch closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulb A current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb B current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb C current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Current</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Use your measurements to help explain the brightness rankings from question B#1.

3. Does your rule for current from question C#5 of the previous investigation still work to explain what happens at the junction point (J) when the switch is open? What about when it is closed?

4. Complete the chart showing measurements of the voltages across the battery and bulbs when the switch is both open and closed.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Switch open</th>
<th>Switch closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total battery voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb A voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb B voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb C voltage</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Draw two complete paths or loops through which current can flow when the switch is closed. Use different colours. For simplicity, choose two paths that pass through the battery.

6. Does your voltage rule from question E#3 of the “Bulbs in Series” investigation still work for each loop when the switch is closed? Explain.

7. Imagine we could follow a single charge through the circuit. Describe how it gains and loses energy in each element of the circuit and describe how this agrees with your voltage rule.
1. Consider circuit 2 and 3 below.
   (a) How does the voltage across the top bulb in each circuit compare to the voltage across the bottom bulb in each circuit?

   (b) How does the current through the top bulb in each circuit compare to the current through the bottom bulb in each circuit?

   (c) Compare the current through the bulbs for the three circuits shown. In which circuit is the current through the bulbs greatest? the least? In which circuit is the voltage across the pair of bulbs the greatest? the least?

2. Determine the voltage across the lettered elements in the following circuits. All bulbs are identical. Explain your reasoning.
SPH3U: Resistance and Ohm’s Law

We have explored the effects of a potential difference on a light bulb – current flows and the bulb lights up. But we have not yet answered one key question: for a given bulb or element of a circuit, how much current will flow due to a potential difference? It is time to answer this question.

A: Current through a Resistor

A resistor is a special circuit element (often made from metal or carbon) that has the same resistance value no matter how much current flows through it. We change the potential difference across our resistor and measure the amount of current that flows through.

1. A single resistor is connected to a single battery. As we increase the voltage of the battery, predict what will happen to the current flowing through the resistor. Explain. Sketch a graph of your predicted relationship.

2. Construct a circuit to test your prediction. You can either adjust the voltage of the battery or connect more batteries in series. Set up a voltmeter to measure the voltage drop across the resistor and an ammeter to measure the current through the resistor. Sketch your circuit below. Record your data in the table.

3. Graph your results with the current on the horizontal axis. Calculate the slope including units. What is the significance of the slope of the graph?

4. Aside from the change in axes, how does the shape of your graph compare with your predictions?

The resistance of a circuit element is defined as $R = \Delta V/I$, where $\Delta V$ is the potential difference across the element and $I$ is the current flowing through it. When the potential difference is measured in volts and the current in amperes, the unit of resistance is the ohm (Ω, the greek letter ‘omega’). One amp of current flowing through an element with a 1 ohm resistance will lose 1 J of energy.

5. Based on your graph, what can you say about the value $R$ for a resistor – is it constant, or does it change as the current flowing through it changes?
When a circuit element, like the resistor, has the same resistance over a wide range of conditions, it is called *ohmic*. This is because it obeys *Ohm’s law*, \( \Delta V = IR \). Ohm’s law shows that the current \( I \) flowing through an element in a circuit is proportional to \( \Delta V \).

**B: Resistors in Series**

1. Imagine we connect three *different* resistors in series. What do you think the total, or *equivalent resistance* to the flow of electrical current of the three resistors will be equal to? Explain using your previous observations with bulbs and batteries.

2. Construct the circuit shown to the right. Label the three resistors with their values (right click to change resistances).

3. Describe the method you are using to predict the equivalent resistance (use the symbols \( R_1, R_2 \) and \( R_3 \)) and then calculate the value.

\[
\text{Predicted } R_{\text{eq}} = ________ \, \Omega
\]

4. Measure the voltage across the battery and current through the battery. Record these measurements below the symbol for the battery.

5. Since we know the current and voltage for the battery, we can use Ohm’s Law to calculate the total resistance the battery experiences due to the three resistors. Show your work.

Note that the total resistance means the total resistance of the circuit the battery is connected to and *not* the resistance of the battery.

6. How does the total resistance experienced by the battery compare with your prediction for the equivalent resistance of the three resistors?

7. On the basis of your experimental results, devise a general mathematical equation that describes the equivalent resistance when \( n \) different resistors are wired in series. Use the notation \( R_{\text{eq}} \) and \( R_1, R_2, \ldots, R_n \) in your equation.

**C: Resistors in Parallel**

1. Imagine we connect two identical resistors in parallel. Would the total resistance be greater than, less than or the same as a single resistor? Explain.

2. Choose two identical resistors. Predict what you think the total resistance of the two will be when wired in parallel. Explain your prediction. If you are not sure, make a guess and move on.
3. Construct the circuit shown to the right. Label the two resistors with their values. Measure the voltage across the battery and current through the battery. Record these measurements beside the symbol for the battery.

4. Since we know the current and voltage for the battery, we can use Ohm’s Law to calculate the total resistance the battery experiences due to the two resistors. Show your work.

5. How does the total resistance experienced by the battery compare with your prediction for the equivalent resistance of the two resistors?

The equivalent resistance of a group of resistors connected in parallel is given by the expression:

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots
\]

When connecting resistors in parallel, the equivalent resistance decreases.

Homework: Electrical Connections

An important skill for understanding electrical circuits is being able to recognize when two circuits that are drawn differently actually function in the same way.

1. Consider the following dispute between two students. Which student is correct? Who you agree with. Why?

   Student 1: “Circuit 1 and circuit 2 are different circuits. In circuit 2 the bulbs are the same distance from the battery, but in circuit 1 one bulb is closer to the battery. So the brightness of the bulbs could be different in the two circuits.”

   Student 2: “Circuit diagrams don’t show physical layout, only electrical connections. In each diagram, the electrical connections are the same. There is a direct path from the positive battery terminal to each bulb. And each bulb is then connected directly to the negative battery terminal. So the brightness of the bulbs will be the same in each circuit. Both diagrams represent the same circuit.”

We can decide whether circuits are equivalent by following the paths from one circuit element to another and check whether the same connections are present.

2. Are the two circuits shown to the right equivalent? Explain.

3. Which circuits below are equivalent?
The electrical circuits found in most electronic devices consist of many different elements combined in combinations of series and parallel networks. A network is just a part of a larger circuit and does not necessarily form a complete loop or closed circuit. We can analyze complicated circuits by identifying smaller parts or networks whose parts are connected strictly in series or parallel and decompose the complex circuit into simpler parts.

**A: Find the Networks**

Here is a complex circuit! It contains one 9.0 V battery and seven identical 100 $\Omega$ resistors. To find the equivalent resistance of all seven resistors we must proceed in steps:

- Identify a network of two or more resistors that are connected strictly in series or parallel
- Find the equivalent resistance of the network
- Replace the network by a single resistor of that value
- Repeat the process until there is only one resistor left

1. Examine the circuit. Are there any resistors connected in series?
2. Are there any resistors connected in parallel?

It is usually best to start with elements deepest in the circuit and work outwards. Resistors 4 and 5 are an example of two connected in parallel.

3. Draw a box around the network of resistors 4 and 5. Determine the equivalent resistance of this network. Use the symbol $R_{45}$ for their equivalent resistance. Show your work here.

4. Write $R_{45} = 50 \, \Omega$ next to the box. You should now think of that box as a single resistor with a resistance of 50 $\Omega$.

5. Continue this process. Your boxes will become larger and larger (draw them neatly so things don’t get too messy!) Show all your calculation below. Be sure to label the equivalent resistance of each box.

6. What is the total resistance the battery will experience? Calculate the current flowing through the battery. Show your work.

7.
Consider the discussion about the circuit shown to the right.

Student 1 says: “I can’t decompose this circuit into series and parallel parts.”

Student 2 says: “You have to take it step by step. 1 and 2 are in parallel. Let’s call that A. 4 and 5 are in parallel. Let’s call that B. Then A and 3 and B are one after another in series.”

Student 2 is not correct. Describe the errors that student 2 has made.

8. Find the equivalent resistance of the circuit to the right. Each resistor has a resistance of 30 Ω. Show your work.

9. Is the circuit above basically a series circuit or a parallel circuit?

10. Suppose the resistance of resistor 5 is increased. Explain in detail, but without numbers:
    (d) what happens to the current through resistor 1?
    
    (e) what happens to the current through the battery?
Throughout this unit, we have been developing a set of rules which help us understand what happens to voltage and current in more complicated circuits. Today we put all this together in the form of two powerful laws.

A: Kirchhoff’s Current Law – The Junction Law

1. Consider the diagram of a junction to the right. 6 amps of current flows into the junction and 4 amps flows out of the junction along one path. Explain how much current flows through the third path and in what direction.

2. The diagram to the right shows another junction. In terms of the quantities $I_1$, $I_2$, $I_3$, and $I_4$, how much current is travelling into the junction? How much is travelling out of the junction?

3. How should the total current travelling into the junction compare with the total current travelling out of the junction? Why?

4. Write an algebraic equation that describes how the currents into and out of the junction are related.

The total current flowing out of a junction is equal to the total current flowing into a junction. This is known as Kirchhoff’s Junction or Current Law. It is an expression of the idea of the conservation of charge – charge at any point in a closed circuit can’t be gained or lost. This means that the total number of amperes flowing into a junction must equal the total number of amperes flowing out.

B: Using the Current Law

To use the current law, choose a point in the circuit as your junction. Make a guess for the direction of the current along each path connecting to the junction. Write out an algebraic equation for the current going into and out of the junction.

1. The diagram to the right shows a more complicated circuit with four identical bulbs. Determine the amount of current flowing through each bulb. Use symbols like $I_K$ to represent the current flowing through bulb $K$.

2. The circuit to the right consists of a variety of different circuit elements, represented by the various shapes. Find the current through elements $M$ and $N$. 
C: Kirchhoff’s Voltage Law – The Loop Law

The circuit shown to the right consists of three resistors and a 10 V battery.

1. Use two colours to draw two different loops in the circuit that both pass through the battery.

2. Consider the loop that contains resistor 2 and 3. Which elements in this loop will the current pass through and gain energy? In which will they lose energy? In which will they lose the most? Explain.

3. Write an equation using the symbols $V_b$, $V_2$ and $V_3$ that relates the total voltage rise with total voltage drop in the loop.

4. Write a similar equation for the other loop of the circuit.

5. Build the circuit and measure the voltages of each resistor. Record these values on the diagram. Verify whether the two voltage equations you created in the previous questions hold true.

In any loop of a circuit, the total voltage rise equals the total voltage drop. This is known as Kirchhoff’s Voltage or Loop Law. It is an expression of the law of conservation of energy in an electric circuit – any energy gained by the charges through the source is lost through the other elements of the circuit. For simplicity, we choose loops that contain the source, but this is not necessary.

6. There are two paths in the circuit between junction points A and B. Compare the total voltage drop along each path.

An alternative way of using the loop law is to notice that the sum of the voltages along any path is the same for all paths between two points.

7. We did not predict the voltages of $R_1$ and $R_3$, we simply measured them. If we didn’t have these readings, how could we predict these individual voltages? One way is to use Kirchoff’s current law to find the current through those resisters and then use Ohm’s law to calculation the voltages. Can you think of a second way?

8. The circuit to the right contains six identical light bulbs. Find the voltage of all the bulbs. For certain bulbs it is easier to use the path trick mentioned above, for others analyze the whole loop. Show your work carefully by writing down the algebraic equations.

Adapted from *Physics by Inquiry*, McDermott and PEG U. Wash, © John Wiley and Sons, 1996
SPH3U: Circuit Analysis

We have developed a complete set of tool to help us analyze simple electric circuits. In this investigation, you will learn how to apply all of them to completely analyze an electric circuit.

A: Your Toolbox – Rules for Electric Circuits
Summarize the tools that you will use to analyze a circuit. For each situation listed below, describe the rule or “tool” you would use to analyze that situation and include a simple equation as an example.

1. The total resistance of elements connected in series:

2. The total resistance of elements connected in parallel:

3. Current flowing in and out of a junction:

4. Voltage rise or drops along a circuit loop:

5. Relationship between current, voltage and resistance for a single element:

B: Circuit Analysis – A Walk Through
Let’s walk through one example together which is a circuit we have studied earlier. There are two good habits we would like to cultivate: (1) record the results of your calculations along side the circuit element, and (2) carefully show your logic using algebraic equations.

1. Examine the information you are given. Since we know the resistances, we can find the total resistance of the entire circuit \( R_T = R_{123} \). Find this now.

2. When we know two quantities about a circuit element, we can always find the third using Ohm’s Law. Try this.

3. The current divides after leaving the battery. We don’t want to guess how much goes along each branch of the circuit – we want to calculate this. We can if we know the voltage of \( R_1 \). Use the voltage law to find \( V_1 \) and the find \( I_1 \).

4. Use the current law to find \( I_2 \) and \( I_3 \).

5. Calculate the voltages \( V_2 \) and \( V_3 \).
C: Circuit Analysis

Now it’s your turn! Completely analyze each circuit by finding the current, voltage and resistance for every element. Always show your work.

Super Challenge Problem: A 3 amp current enters the resistor cube through wire A shown to the right. What is the equivalent resistance of the cube? What is voltage drop across each 1 Ω resistor?
SPH3U: Magnetism!

I. Magnetic materials
   A. Investigate the objects that you have been given (magnets, metals, cork, plastic, wood, etc.). Separate the objects into three classes based on their interactions with each other.

   1. List the objects in each of your classes.
      
      Class 1                  Class 2                  Class 3

   2. Fill out the table below with a word or two describing the interaction between members of the same and different classes.

      Table of Interactions
      
      | Class 1 | Class 2 | Class 3 |
      |---------|---------|---------|
      |         |         |         |
      |         |         |         |
      |         |         |         |

   3. Are all metals in the same class?

   4. To which class do magnets belong? Are all the objects in this class magnets?

   1. Use the compass to explore the region around a bar magnet.

      Describe the behavior of the compass needle both near the poles of the magnet and in the region between the poles.

      To which class of objects from section I does the compass needle belong? Explain.
Place the bar magnet over the outline below. Position the compass at each circle and draw the direction of the compass needle at that position.

2. Move the compass far away from all other objects. Shake the compass and describe the behavior of the compass needle.

Does the needle behave as if it is in a magnetic field?

We can account for the behavior of the compass needle by supposing that it interacts with the Earth and that the Earth belongs to one of the categories from section I.

To which class of objects from section I do your observations suggest the Earth belongs? Explain how you can tell.

3. We define the north pole of a magnet as the end that points toward the arctic region of the Earth when the magnet is free to rotate and is not interacting with other nearby objects.

On the basis of this definition, is the geographic north pole of the Earth a magnetic north pole or a magnetic south pole?

Use your compass to identify the north pole of an unmarked bar magnet.
A: Magnetic Forces on Static Charges
Let’s start by investigating the forces on static electric charges. We will use “Magic Tape” that has a static electric charge. You need: “Magic Tape”, 1 bar magnet, 1 non-magnetized rod

1. Peel of a piece of tape about 15 cm long. Attach one end to a pencil so it hangs freely. What evidence is there that suggests the tape has a static electric charge?

2. Test to see if there is any force on the electrically charged tape from either pole of your magnet. Do the same test with a non-magnetized bar or rod. Summarize your findings.

3. If the charged tape is attracted to both the magnetic and non-magnetic bar in the same way, can you conclude that there is any special interaction or force between either of the magnetic poles and the tape?

B: Magnetic Forces on Moving Charges
You need a hobby magnet, a compass, a 9V battery, two paper clips, two wire leads and a U shaped wire.

1. Stand the hobby magnet up on end. Move the compass around the magnet and determine the location of the north and south poles. (If there are already markings, confirm that another group didn’t get it wrong!) Mark the surface of the magnet with an “N” using chalk. Show this in the drawing to the right. Draw the magnetic field lines that travel in and out of these surfaces.

Set up the equipment as shown in the diagram to the right making sure the U can swing freely. Place the magnet with north facing up.

2. Connect the two leads to the battery. Carefully describe what you observe. Do not leave the battery connected!

3. Since you have the north pole of the magnet facing up, the magnetic field lines just above the surface of the magnet also point directly upwards. In the first diagram below to the right, the magnet, the field lines and the wire are shown. Draw an arrow showing the direction of the (conventional) current flow and the force that the wire experienced.

4.
Turn over the magnet such that the south pole is facing upwards. Connect the battery. Describe your observations.

5. Complete the second diagram showing the direction of the magnetic field, the current and the force.

6. Continue with the south pole of the magnet upwards. Switch the leads of the battery, reversing which one was connected to the positive and the negative terminals. Describe your observations.

7. Complete the third diagram showing the direction of the magnetic field, the current and the force.

8. Explain what quantities affect the direction of the force experienced by a wire in a magnetic field.

9. In the three situations we have explored, how do the directions of the magnetic field, the current and the force compare with one another?

10. Suggest what characteristics of your experiment could your change in order to increase the size of the force.

Electric charges moving perpendicular to a magnetic field will experience a force. This force is called the Lorentz force which you will learn more about in Grade 12. This general principle is known as the motor principle since it is the phenomenon responsible for making electric motors work. Charges at rest in a fixed magnetic field do not experience any force.

C: The Right-Hand Rule for the Motor Principle

The relationship between the direction of the magnetic field, the current and the Lorentz force can be shown by using the right-hand rule for the motor principle. Stretch out your right hand flat. The direction of your fingers corresponds to the direction of the magnetic field lines (from north to south). The direction of your thumb shows the current and the direction of your palm gives the force.
1. Each diagram below shows a horseshoe magnet and a wire with current that runs between the north and south pole of the magnet. Complete the missing parts of the diagrams: direction of the electron current, magnet polarity or force. Use the symbol for a vector pointing out of the page, and use the symbol for a vector pointing into the page.

   ![Diagram with symbols](Image)

2. The diagrams to the right show four motors: two from a top view and two from a side view. Each motor consists of a loop of wire carrying a current and a pair of field magnets. Show the direction of the force on each half of the loop and indicate the direction in which the loop will turn.

   ![Motor Diagrams](Image)

B. A small current loop is placed near the end of a large magnet as shown.

1. Draw vectors to show the magnetic force on each side of the loop.

   What is the net effect of the magnetic forces exerted on the loop?

2. Suppose that the loop were to rotate until oriented as shown.

   Now, what is the net effect of the magnetic forces exerted on the loop?
SPH3U: The Motor Project!

For this project you are responsible for bringing:
- one piece of wood (about 15 cm x 20 cm, not compressed wood)
- four 4-inch nails

You really should consider finding:
- something to use as the axel for your motor (preferably non-magnetic)
- something to use as the brushes of your motor (soft, flexible metal)

Construction Instructions
1. Carefully place a straightened paperclip through the centre of each end of your cork. This will act as the axel.
2. On one end of the cork place two pins as shown in the diagram to the right. These will be your commutators.
3. Bare one end of the wire and wrap the bared section around one of the commutator pins. Then wrap the wire around the cork as shown to the right above. The other end of the wire should also be bared and wrapped around the other commutator pin.
4. Build bearings out of paper clips as shown and mount them on the wooden base using thumb tacks. Mount the cork in the bearings.
5. Make brushes out of metal strips or wires and attach them using thumb tacks.
6. Mount magnets on nail holders with opposite poles facing each other. (attracting!)
7. Connect the power supply and give your motor a spin, it should work!

Marking!  Speed – 100%
If your motor turns, you pass!