PHYSICS 121.1 APPENDICES

Physics
AT QUEENS COLLEGE

PHYSICS 121.1
APPENDIX A: LABORATORY PROTOCOL AND PROCEDURE

LABORATORY PROTOCOL AND PROCEDURE

LAB MANUAL

Before coming to lab: Your course syllabus will indicate which lab exercise is scheduled for the week.

☐ Go to the Queens College Physics Department Website, at: http://www.physics.qc.edu/.
On the top bar, click on Current Students. On the new screen, click on Downloadable Files (third on the list). Now, on the new screen, click on your class, select the lab scheduled for the coming week, and print the file. You may also have to print some of the appendices; the lab will list those that you must consult.

☐ Read the lab **thoroughly**. You may want to consult your textbook: the lab will give you the pages that cover the material.

PRELAB ASSIGNMENTS

Log into Blackboard, and answer the pre-lab questions based on the reading. This will count toward your lab grade. The prelab questions will appear right after the previous lab, and disappear before you do the lab. The exact times will be supplied by your lab teacher.

BE PROMPT

This will give you the maximum opportunity to finish all parts of the laboratory exercise. The first step is to examine the equipment, and if the equipment is obviously or faulty in some way, ask your lab instructor for assistance.

WORK ETHIC

Work slowly, steadily and carefully: If you are sloppy in doing the lab, your results (not to mention your grade) will be poor. Pay attention to recording your data in the right place, with the correct significant digits.

ACADEMIC INTEGRITY

Honesty is important: Do not copy data, conclusions, or computations from any source including your lab partner. Bear a proportionate share of the responsibilities of performing the experiments.

Note: Any form of academic dishonesty will not be tolerated and will be dealt with in accordance with the policy set forth by the college.

LAB ETIQUETTE

Follow the rules of the lab

☐ No food or drink is allowed in the lab! Ever!
☐ Turn your cell phone off before coming into the lab, and leave it off. If you must make a call, you must leave the lab.

☐ Avoid sudden loud noises. If you want to talk to someone across the room: go there!

GRADING RUBRIC

☐ 15% - Pre-labs
☐ 25% - Lab practical. The practical is a final exam given during finals week.
☐ 60% - Lab reports. The report is done entirely during the two hours lab period; grades are based on the data you collect, how you analyze that data, and questions at the end of the lab.

AT THE END OF EACH LAB:

☐ Turn off all electronic devices
☐ Leave your station as you found it; place all apparatus neatly at your laboratory station.
☐ Staple your lab report and the answers to the questions at the end of the lab. No lab report will be accepted after the lab is over.
☐ Sign the attendance sheet.

PHYSICS 121.1
APPENDIX B: UNCERTAINTY

MEANING OF UNCERTAINTY

Suppose you ask three students to measure the height of a building:

- Student A estimates the height by eye as $50\ m$, give or take a few meters.

- Student B holds a rope off the roof and then measures the length of the rope with a measuring tape marked in centimeters, and gets an answer of $50.23\ m$.

- Student C uses a very accurate surveying device called a transit, and gets an answer of $50.229\ m$.

These measurements differ in their accuracy, a result of the measuring devices used. This accuracy should be indicated in the way a result is written. The accuracy of a measurement is expressed by its **uncertainty**:

- Student A's estimate is highly inaccurate. If we assume that his "guess" is within $3\ m$ of the right answer, the actual height could be anything from $47\ m$ to $53\ m$. This value is expressed as $50\ m \pm 3\ m$. ($50\ m$, with an uncertainty of $3\ m$ either way).

- Student B's measurement is accurate to the hundredths place (since the smallest unit marked on the tape is a centimeter, one hundredth of a meter). The uncertainty is one-half of the smallest measuring unit, or $0.005\ m$ either way. The actual height cannot be $50.22\ m$ or $50.24\ m$, but might be anything from $50.225\ m$ or $50.235\ m$. This is expressed as $50.23\ m \pm 0.005\ m$.

- Student C's measurement is accurate to the thousandths place, so the uncertainty is one half of this, or five ten-thousandths. This value is expressed as $50.229\ m \pm 0.0005\ m$ ($50.229\ m$, with an uncertainty of $0.0005\ m$ either way).

If a measurement is less than the uncertainty, it is meaningless!

UNCERTAINTY IN MEASURING DEVICES

Any measuring instrument is specifically designed to measure something, whether it is mass or length or electric current. You always want to know how accurate each measurement is, in other words, the uncertainty in the measurement.

For a ruler is marked off only in centimeters: any measurement of length that is not exactly a whole number of centimeters involves an estimate. For such a ruler, the uncertainty is $\pm 1/2\ cm$ (or $\pm 0.5\ cm$). For a ruler marked off in millimeters ($10\ mm = 1\ cm$): the uncertainty is $\pm 1/2\ mm$ (or $\pm 0.05\ cm$).

Rule of thumb: Unless otherwise specified, the uncertainty in a device is one-half of the smallest unit on the scale. A sensor that reads two decimal places is assumed to have the uncertainty in the third place, or ± 0.005. If it reads to three decimal places, the uncertainty is in the fourth place, or ± 0.0005.

SYSTEMATIC ERRORS VS. RANDOM ERRORS

Systematic errors are errors caused by a design flaw in your experiment. ***Example***: if you use a ruler which has the centimeter marks too close together; you will consistently get measurements that are too large.

Example: In motion experiments, friction is usually ignored. Since friction is never zero, this can introduce a systematic error into your experiment. Of course, systematic errors should be minimized, and eliminated if possible. For example: we can eliminate the first problem by using a properly calibrated ruler. In the second problem: we cannot eliminate friction, but we can reduce it by using carts with wheels instead of letting them slide across a surface.

Random errors are simply experimental errors caused by random effects. One example: an electrical reading might be affected by random fluctuations in the power line. Another example: workmen outside your lab may introduce vibrations in the floor that cause slight variations in the readings on a mechanical device.

CALCULATIONS AND UNCERTAINTIES:

In calculations, we must combine numbers with uncertainties, and we need to know the uncertainty in the result. In all of the following, we assume that the variables used in the calculation do not depend on each other. The methods presented give the expected uncertainty in a calculated quantity.

Note: For any variable x, *we will use the notation* Δx *for its uncertainty. Values are written:* $x \pm \Delta x$.

A calculator might give eight or nine decimal places for an answer, but you only need numbers that are significant.

Rule of thumb: use two non-zero places for the uncertainty, and keep all the places in your answer up to the last digit in the uncertainty. For example, if a calculation gives 3.3333333 *with an uncertainty of* ± 0.4592232, *your answer is* 3.33 ± 0.46. *If the same calculation has an uncertainty of* ± 0.04592232, *the answer is* 3.333 ± 0.046

If a measured value is zero, the uncertainty is still the uncertainty of the measuring device. For example: if a measuring device with uncertainty ± 0.005, then if it reads a value of zero, it is recorded as 0.000 ± 0.005.

ADDITION AND SUBTRACTION:

If $w = x + y$ or $w = x - y$, then $\Delta w = \sqrt{(\Delta x)^2 + (\Delta y)^2}$

EXAMPLE:

w = (5.00 ± 0.20) + (3.00 ± 0.50)

The result is *w* = 8.00

To find the uncertainty in the result, $\Delta w = \sqrt{(0.2)^2 + (0.5)^2} = 0.539$

The complete answer: $w = 8.00 \pm 0.54$

EXAMPLE:

$(5.000 \pm 0.020) - (3.000 \pm 0.050) = 2.000 \pm 0.054$

If you add the same measurement, $x \pm \Delta x$, twice, the result is 2*x* ± 2Δ*x* (because these numbers depend on each other!) However, if you add two different, independent, measurements $(x \pm \Delta x) + (y \pm \Delta y)$, even if they have the same value and uncertainty, the result is $(x + y) \pm \sqrt{(\Delta x)^2 + (\Delta y)^2}$

For $w = xy$, then $\Delta w = \sqrt{(x\Delta y)^2 + (y\Delta x)^2}$

EXAMPLE:

$w = (5.00 \pm 0.2)(3.00 \pm 0.5)$, the product is 15.0.

To find the uncertainty: $\Delta w = \sqrt{[5.00(0.5)]^2 + [3.00(0.2)]^2} = 2.57$

The product with its error is therefore 15.0 ± 2.6

If one of the numbers (say, a) is exact (which has an uncertainty of zero). Using our formula: since $\Delta a = 0$, we obtain $\Delta w = a\Delta y$

EXAMPLE:

If $w = 3(5.00 \pm 0.02)$, then $w = 15.00 \pm 0.06$

As with addition, if you multiply the same measurement by itself ($w = x^2$), the error is not found by the formula, but: $\Delta w = 2x\Delta x$. However, If you multiply two independent measurements $(x \pm \Delta x) + (y \pm \Delta y)$, even if they have the same value and uncertainty, the uncertainty is found using: $\Delta w = \sqrt{(x\Delta y)^2 + (y\Delta x)^2}$

Example:

If $w = (5.00 \pm 0.02)^2$, then $w^2 = 25 \pm 2(5)0.02 = 25.00 \pm 0.2$

To multiply three quantities: $w = xyz$, the uncertainty is: $\Delta w = \sqrt{(xy\Delta z)^2 + (xz\Delta y)^2 + (yz\Delta x)^2}$

When multiplying two numbers: if one of them has a value zero, the product is zero but the uncertainty in the product is not **unless** the zero value also has an uncertainty of zero.

EXAMPLE:

For $w = xy$, where $x = 0.00 \pm 0.05$ and $y = 2.00 \pm 0.05$

The uncertainty is: $\Delta w = \sqrt{(x\Delta y)^2 + (y\Delta x)^2} = y\Delta x = 2(0.05) = 0.10$, and $w = 0.00 \pm 0.10$

Division:

$w = \dfrac{x}{y}; \quad \Delta w = \dfrac{\sqrt{(y\Delta x)^2 + (x\Delta y)^2}}{y^2}$

Using this for an exact value, a:

$w = \dfrac{a}{y}; \quad \Delta w = \dfrac{a\Delta y}{y^2}$

POWERS

$$w = x^n; \quad \Delta w = nx^{n-1}\Delta x$$

For example:

$$w = \sqrt{x}; \quad \Delta w = \frac{1}{2}x^{-1/2}\Delta x = \frac{\Delta x}{2\sqrt{x}}$$

$w = \sqrt{x}$ where $x = 5.00 \pm 0.02$, the uncertainty is:

$$\Delta w = \frac{\Delta x}{2\sqrt{x}} = \frac{0.02}{2\sqrt{5}} = 0.045$$

Therefore: $w = 2.236 \pm 0.045$

TRIGONOMETRIC FUNCTIONS:

Any well behaved function can be expressed as a polynomial series in terms of a deviation, Δx, from a point x_0 as:

$$f(x_0 + \Delta x) = \sum_{n=0}^{\infty} \frac{f^{(n)}(x_0)}{n!}(\Delta x)^n = f(x_0) + f'(x_0)\Delta x + \frac{1}{2}f''(\Delta x)^2 + \cdots$$

This can be used to estimate the how the error (Δx) in a variable (x) propagates through a function $f(x)$. Since the errors are generally small compared to the variable itself, i.e., $|\Delta x/x_0| \ll 1$, we will only the first order term:

$$\Delta f = f(x_0 + \Delta x) - f(x_0) \approx f'(x_0)\Delta x$$

For commonly used trigonometric functions, the error has the following form:

$f(x)$	$\Delta f \approx f'(x_0)\Delta x$	$f(x_0) \pm \Delta f$
$\sin x$	$\cos(x_0)\,\Delta x$	$\sin(x_0) \pm \cos(x_0)\,\Delta x$
$\cos x$	$\sin(x_0)\,\Delta x$	$\cos(x_0) \pm \sin(x_0)\,\Delta x$
$\tan x$	$\sec^2(x_0)\,\Delta x$	$\tan(x_0) \pm \sec^2(x_0)\,\Delta x$

The error functions given in the above table can be used only if the error, Δx, is in radians. The following table can be used for angles in degrees:

$f(x)$	$\Delta f \approx f'(x_0)\dfrac{\pi}{180°}\Delta x$	$f(x_0) \pm \Delta f$
$\sin x$	$\cos(x_0)\dfrac{\pi}{180°}\Delta x$	$\sin(x_0) \pm \cos(x_0)\dfrac{\pi}{180°}\Delta x$
$\cos x$	$\sin(x_0)\dfrac{\pi}{180°}\Delta x$	$\cos(x_0) \pm \sin(x_0)\dfrac{\pi}{180°}\Delta x$
$\tan x$	$\sec^2(x_0)\dfrac{\pi}{180°}\Delta x$	$\tan(x_0) \pm \sec^2(x_0)\dfrac{\pi}{180°}\Delta x$

Note that the error terms, Δf, should be taken as $|\Delta f|$ since it specifies an error range given by $\pm\Delta f$

For angle $\theta = 55° \pm 15°$ calculate the error in $\sin \theta$:

Solution:

$$\sin(\theta \pm \Delta\theta) = \sin\theta_0 \pm \cos(\Delta\theta)\frac{\pi}{180}\Delta\theta = \sin 55° \pm \cos(55°)\frac{\pi}{180°}(15°)$$

$$= 0.82 \pm (0.57)\left(\frac{\pi}{180°}\right)(15°) = 0.82 \pm 0.15$$

PRACTICAL EXAMPLE:

When calculating uncertainty for variables with a complex formula: break up the problem into small steps

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EXAMPLE:

Suppose you want to calculate the acceleration of an object using the following values:

Initial speed of the object: $v_i = 1.220 \pm 0.063 \ m/s$

Final speed of the object: $v_f = 2.670 \pm 0.041 \ m/s$

Displacement the object: $x = 8.3201 \ m \pm 0.0053 \ m$

First, the acceleration, a, can be found by the kinematics equation:

$$v_f^2 = v_i^2 + 2a\Delta x$$

$$a = \frac{v_f^2 - v_i^2}{2x} = \frac{(2.67 \ m/s)^2 - (1.22 \ m/s)^2}{2(8.3201 \ m)} = 0.3390 \ m/s^2$$

To find the uncertainty in a, break the problem up into small pieces:

- First, find the uncertainty in v^2: use the equation (from above) that the uncertainty in a quantity squared is given by: $\Delta(v^2) = 2v\Delta v$

  - The uncertainty $\Delta(v_i^2) = 2(1.22 \ m/s)(0.063 \ m/s) = 0.154 \ m^2/s^2$

  - The uncertainty $\Delta(v_f^2) = 2(2.67 \ m/s)(0.041 \ m/s) = 0.219 \ m^2/s^2$

- The uncertainty in the denominator, $2x$ is twice the uncertainty in x:
  $\Delta(2x) = 2(0.0053 \ m) = 0.0106$

- The uncertainty $\Delta(v_f^2 - v_i^2)$ is the uncertainty between two values for which we know the uncertainty:

$$\Delta(v_f^2 - v_i^2) = \sqrt{\left[\Delta(v_f^2)\right]^2 + [\Delta(v_i^2)]^2} = \sqrt{[0.154 \ m^2/s^2]^2 + [0.219 \ m^2/s^2]^2} = 0.268 \ m^2/s^2$$

- Finally, $a = \frac{y}{z}$, where:

$$y = v_f^2 - v_i^2 = 5.641 \ m^2/s^2 \pm 0.268 \ m^2/s^2, \qquad z = 2x = 16.640 \ m \pm 0.0106 \ m$$

Therefore:

$$\Delta a = \frac{\sqrt{(z\Delta y)^2 + (y\Delta z)^2}}{z^2}$$

$$= \frac{\sqrt{[(16.640\ m)(0.268\ m^2/s^2)]^2 + [(5.641\ m^2/s^2)(0.0.0106\ m)]^2}}{(16.640\ m)^2} = 0.0161\ m/s^2$$

The acceleration is:

$$a = 0.3390\ m/s^2 \pm 0.0161\ m/s^2$$

PHYSICS 121.1
APPENDIX C: PERCENT ERROR & PERCENT DIFFERENCE

ERRORS

No experiment is perfect, and quantities measured by any experiment are never precisely correct. No matter how carefully you avoid design and systematic errors, there will always be experimental error. This is due to many factors:

- Uncertainty introduced by the measuring device

- Inaccuracies caused by the difficulty in measurement, etc.

Sometimes you will want to see how far "off" your experimental value is from an established value, or compare two values of the same quantity found by different methods. It is meaningless to simply find the difference:

- If you are measuring the value of π(3.14159…) and your answer is off by 1, this is a tremendous error because it is a large percentage of the actual value (31.8%)

- If you are measuring the radius of the Earth (6378 km) and you are off 1 km, this is a tiny error because it is a very small percentage of the actual value (0.00157%)

PERCENT ERROR

If you want to compare your experimental value with an accepted value, we use **percent error**:

$$\text{Percent Error} = \left|\frac{\text{Experimental Value} - \text{Accepted Value}}{\text{Accepted Value}}\right| \times 100\%$$
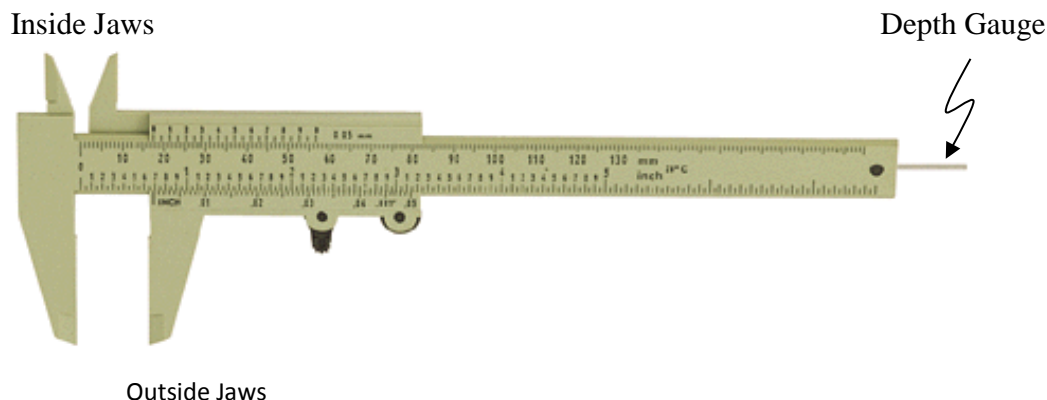
This value tells you by what percentage your experimental value differs from the accepted value.

PERCENT DIFFERENCE

Sometimes you want to compare two values, perhaps both experimental. This is done by comparing the difference between the values (in the numerator) with the average of the values (in the denominator). This is **percent difference**:

$$\text{Percent Difference} = \left|\frac{\text{Difference in Values}}{\text{Average Value}}\right| = \left|\frac{\text{Value}_2 - \text{Value}_1}{\left(\frac{\text{Value}_1 + \text{Value}_2}{2}\right)}\right| \times 100\% = 2\left|\frac{\text{Value}_2 - \text{Value}_1}{\text{Value}_1 + \text{Value}_2}\right| \times 100\%$$

☺Physics
AT QUEENS COLLEGE

VERNIER CALIPER

Inside Jaws   Depth Gauge

Outside Jaws

The vernier caliper is a versatile precision measuring instrument (see diagram above) that can give accurate measurements of length.
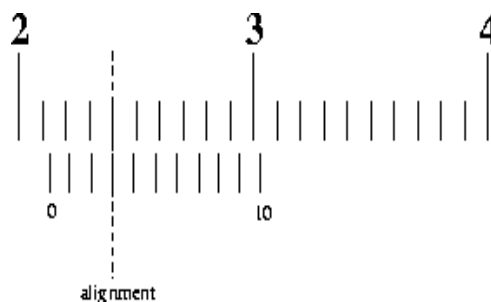
USING VERNIER CALIPERS

- There are two fixed scales on the central ruler: one is metric, the other is in inches. Since all our work is in metric, we will ignore the inch scale. On the metric scale, the boldface numbers on the fixed scale are centimeters, with millimeter (tenths of a centimeter) marked in between.

- If there is a set screw at the top, loosen the screw. Use the wheel at the bottom to open the jaws.

- The moving scale is the **vernier scale**.

- There are **three** ways to use the vernier calipers:

  - You can place an object between the outside jaws (see diagram above) to measure the diameter of an object, or the length of an object. Close the jaws *gently* (so you do not damage the calipers).

  - You can put the inside jaws (see diagram above) inside an opening, and then open the calipers as far as you can. This is used to measure the inside diameter of a cavity.

  - You can use the depth gauge (see diagram above) to measure the depth of a cavity.

READING THE CALIPERS

- The **first two places** are read on the fixed centimeter scale (on the central bar). Look for the 0 on the vernier scale; the first two digits are the numbers before the 0 of the vernier. In the picture below: the first two digits on the fixed scale are 2.1.

- Next we find the hundredths place. Look for the mark on the vernier (sliding) scale that **exactly aligns** with a mark on the fixed scale. The hundredths place is the number on the sliding scale that is aligned. In the above picture: the 3 on the vernier scale is aligned, so the reading is $2.13\ cm$. With uncertainty, this is written: $2.13 \pm 0.005\ cm$.
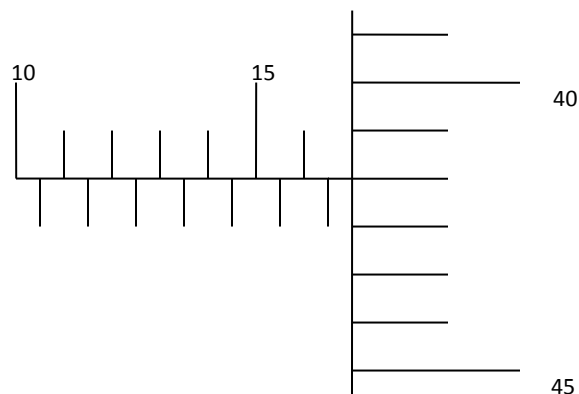
There is a computer simulation on how to use the outside jaws of vernier calipers on the internet at:

http://www.stefanelli.eng.br/en/en-vernier-scale-nonius.html

Unless you are sure you understand how to use the vernier calipers, *watch this video <u>all the way through</u> before you come to lab*!

https://www.youtube.com/watch?v=ZUNoWWw6V10

MICROMETER

THIS IS AN EXTREMELY ACCURATE, HIGH PRECISION PIECE OF EQUIPMENT.

- Use it gently, and place it gently back on the desk when you put it down.

- When measuring the dimensions of an object, close the micrometer *very gently*. The anvils (the opposing faces) should *never* be forced against a surface

- *Never*, *never*, *never* close the micrometer jaws when nothing is inside. The two anvils should never touch each other.

Close the "spindle" (the moving jaw) of the micrometer *gently* on the object to be measured. Then use the "ratchet stop" (on the rightmost end in the picture above) to tighten the spindle.

To get the correct reading, we need to get three different measurements, and add them together:

- First, we need to determine how many major divisions are showing on the upper scale of the barrel. In this picture above (to the right) there are sixteen divisions showing ("15" plus the minor division). This is read as 16 mm.

- On the lower scale of the barrel, each division is 0.5. Since you can see an extra division beyond the "16" on the upper barrel, this adds 0.5 to our reading, making 16.5 mm in all.

- Finally, we read the "thimble". (This is the vertical scale to the far right on the diagram.) Here we are looking for the mark that most closely lines up with the center line. As you can see, the mark that lines up with the center line corresponds with the number "42" (two marks above the 40). This adds 0.42 mm to our reading, so our final answer is 16.5 mm + 0.42 mm = 16.92 mm. Usually we want this answer in cm. To convert to cm: move the decimal place one to the left (or, equivalently, divide by 10). This reading is 1.692 cm. With uncertainty, this is written 1.692 ± 0.0005 cm.

Simulation: http://www.stefanelli.eng.br/en/i-micrometer.html

There is a video on using a micrometer on the internet at: https://www.youtube.com/watch?v=WFAyDGFMfkk

QPhysics
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EXCEL

Excel is a spreadsheet; it allows the user to organize data, do calculations, and produce different types of graphs. This lab will introduce you to a few of the capabilities of this powerful program. If you have time: try other options on the menus and see what they do! This description refers to the version of **Excel** on the computers in the lab.

Your computer may have a different version, and therefore there might be some differences in the organization of menus.

STARTING EXCEL:

Use the **Excel** icon (shown to the right) to open the program. A blank spreadsheet should appear.

NOTE: If there you do not see the icon: click on **START** (in the lower left-hand corner), select **Programs**, select **Microsoft Office**, and then select **Excel**

TERMINOLOGY

On the very top left is a large circular button called the **Office Button**. Clicking here allows you to print or save your file. ***Students should never save work on the lab computers***.

PULL-DOWN MENUS

A series of options at the top of the page: **Home**, **Insert**, **Page Layout**, **Formulas**, **Data**, **Review**, **View**. When you click on one of these words, either a function is performed or a new group of icons will appear below this line.

TOOLBAR

Beneath the pull-down menus; the toolbar is a series of icons   If you point your mouse over an icon, a small box will appear describing its function. If you click on an icon, either a function is performed or a series of icons appears. The exact arrangement of the toolbar icons differs from one computer to another.

CELLS

These are the boxes in the spreadsheet. Columns are labeled at the top: A-Z, then AA-AZ, then BA-BZ, etc. Rows are numbered on the left: 1-65536. You can get around the spreadsheet with the arrow keys or by clicking with the mouse. Each cell is referred to by column and row (ex: B6). A cell can hold a number, a date, text, etc.

HIGHLIGHTING CELLS

- To highlight one cell: use the mouse to click on it.

- To highlight many cells: move the cursor to the first cell; hold down the left mouse button and drag the cursor over all the cells to be highlighted; now release the mouse button.

- To highlight an entire row: click on the row number (on the left).

- To highlight an entire column: click on the column letter (on top).

- To highlight all the cells: click on the box in the upper left corner of the spreadsheet (between column label A and row label 1).

DIALOG BOX

A page of options that appears when you click on an icon or button

ENTERING DATA INTO CELLS

You can put text and numbers into the cells (and many other things besides, but for now this is all we will use.). Suppose we measure the distance a cart has traveled after each second, and record the data in our spreadsheet.

Time (s)	Distance (m)
1	4.7
2	9.2
3	15.8
4	20.1
5	24.6
6	31.0
7	35.8
8	41.2
9	44.3
10	49.8

☐ Click on cell A1 and type TIME (s). If you press **Enter**, the cursor will move down to A2; you can also use the arrow keys or the mouse to change cells.   Go to cell B1: type DISTANCE (m) and press **Enter** (or use the arrow keys to get out of the cell). Note that this title does not fit into the cell.

☐ To change the width of row B (so the title fits in the cell): move your mouse to the top of column B (to the cell with the B in it, above the cell in which you typed DISTANCE). If you move the cursor to the right edge of this box, a black cross will appear.
   - ☐ You can double click; the cells automatically adjusts to just fit the header
   - ☐ You can hold down the left mouse button and slide the cursor; the width of all the cells in the column will increase until you stop moving the mouse and release the left button.

☐ Type each number into a cell, and press **Enter**. Put the values for time (from 0 to 10) in column A (rows 1-11), and the values for distance (shown above) in column B (rows 1-11).

PERFORMING CALCULATIONS

EXCEL, like all spreadsheets, will use the data you have entered to do calculations.

For example: suppose we wish to add a third column showing the average speed of the cart after each second.

☐ Type AVERAGE SPEED (m/s) in cell C1. As before, adjust the column width so the title fits in the cell.

☐ Average speed is the distance divided by time; you must divide the value in column B (in cell B2) by the value in column A (in cell A2). Click on cell C2 and type**: = B2/A2**
Note: Once you enter an equation into a cell, the equation can only be edited in the function tab, a white bar above the screen.

☐ Press **Enter**. The value in cell B2 is divided by the value in cell A2, and the result appears in cell C2.

☐ We can now copy this calculation for each time (in column A) and distance (in column B):
   - ☐ Click on the cell with the calculation you wish to copy (in this case, C2)
   - ☐ Hit **CTRLI-C** to copy the information in this cell. A dashed line should appear around the cell.

☐ Highlight all the boxes in the column for which you want to do this calculation,, and hit **CTRL-V**. Each cell will now use the same formula to calculate average speed: B3/A3 in cell C3, B4/A4 in cell C4, etc.

☐ Hit the **Esc** to get rid of the dashed box.

Suppose want each number in the average speed column (column C) to have three decimal places. Highlight all the cells you have used in column C. Now:

☐ Right click on your mouse, and a menu appears.

☐ Click on **Format Cells**; another dialog box will appear.

☐ Click on **Number**

☐ Now go to the right. In the space labeled **Decimal Places**, change the number in the box clicking on the top arrow (to increase the number) or the bottom arrow (to decrease the number). When it reads 3, go to the bottom and click on **OK**. The dialog box should disappear, and all the numbers in the column now have three decimal places.

☐ If ##### appears in the boxes, it means there is not enough space to display all the decimal places. Just adjust the size of the column until the digits reappear.

There are many other functions available. If column D is to contain the square root of the value in column C:

☐ In cell D2, type: **=sqrt(c2)**

☐ Now, use **CTRL-C** and **CTRL-V**, as before, to do the same calculation in each cell in column D.

You can see a complete list of the available functions (absolute value **ABS**, sine **SIN**, etc.) by going to the Help menu (the question mark on the top right) and search for MATH FUNCTIONS.

Note: We have only scratched the surface of what is possible. If time permits (or, if you have Excel on your computer at home): try some of the other options in the pull down menus, and see what happens.

In many of the labs there are calculations that must be done over and over with different numbers. **Excel** lets you do the same calculation by simply entering a number into a cell (or several numbers into several cells), and the computer does the work for you.

GRAPHING IN EXCEL

To learn how to graph with **Excel**, we will plot distance (on the *y*-axis) vs. time (on the *x*-axis). To bring up the graphing capabilities: click on the **Insert** in the menus at the top; a new set of icons will appear.

☐ Click on **Scatter** (to select a scatter graph).

☐ A dialog box will appear: click on the first icon (a scatter graph that plots the points but does not insert a line). A box should appear on your page.

☐ Click on **Select Data** (on the top, the fourth icon from the left). A dialog box should appear.

☐ Click on **Add**, and a dialog box called **Edit Series** will appear, with the cursor on the first line.

☐ On the first line, type in $s\ vs.\ t$**.**

☐ Use the **Tab** to get to the second line. Highlight the first column (you can do this by clicking on the A at the top).
NOTE: If your data column has a title, you cannot highlight the entire column (because you cannot plot the words). Instead, highlight the cells with data using the mouse.

- ☐ Use the **Tab** to get to the second line. Highlight the second column (or the data in the second column).
- ☐ Click on the **OK** at the bottom.
- ☐ You can add a second graph over the first by clicking on **Add** again, and using different columns of data.
- ☐ There are many options available to you:
    - ☐ If you right click on one of the axes, you can adjust the limits and/or the divisions between the labeled points.
    - ☐ If you right click on one of the data points, you can add a ***trendline***- a best-fit graph. You are given the option of fitting the points to various equations: linear, exponential, polynomial, etc. You can also make the equation for the trendline appear on the graph. When you do this, the equation appears, but the coefficients will be rounded to one or two digits. If you right click on the equation and then on **Format Label**, you can select the form of the coefficients:
        - ▪ You can select **Number** and set the decimal places to 2. Now, $y = 7x + 5$ will appear as $y = 7.00x + 5.00$
        - ▪ Sometimes the coefficients are very small or very large. In that case choose **Scientific**; now the coefficients will have three significant digits with an exponent (so $y = 7x + 5$ will appear as $y = 7.00e00x + 5.00e00$).
        - ▪ You can force the trendline to pass through a specific point on the y-axis: click on **Select Intercept**.
    - ☐ You can label the axes (giving the units, such as m/s, kg, etc.)
    - ☐ You can label the entire graph: when you use **Select Data**, the top box will put a label at the top. Every graph you submit must have a title with your name ***printed*** at the top.

PHOTOGATE

A photocell is a piece of metal that emits electrons when light (not necessarily visible light) hits it. This phenomenon, called the photoelectric effect, was discovered in 1887 by Heinrich Hertz. We will study this effect in the second term of this course.

A photogate consists of a light source (not necessarily visible light) and a photocell: The light shines on the photocell, producing a current. If something opaque passes between the light source and the photocell, the current is interrupted, and an electric signal is produced (and a red light on the photogate housing lights up).

Example: This system is used to open doors, to start escalators, etc.

In our labs, the signal from the photocell is sent to a computer.

MOTION DETECTOR

SONAR

Sonar produces an ultrasonic sound which travels through the water, hits an object, and bounces back (echoes). The echo is detected, and the time for the sound to travel back and forth is measured. This information allows calculation of the distance to an underwater object.

The operation of a motion detector is similar to that of SONAR. A series of audible clicks is produced by the sensor; the sound travels through the air and echoes off the first object the sound hits (which, if nothing is in the way, will be the floor). The echo is detected, and the distance to the floor can be measured by:

Figure 1: image from raymarine.com

- Calculating one-half the time the sound traveled (the time it took the sound to reach the floor).
- If d is the distance to the object, and $t_{1/2}$ is one-half the time the sound was traveling, and v_{sound} is the speed of sound in air, then the distance from the detector to the object can be found using: $s = v_{sound}t$.

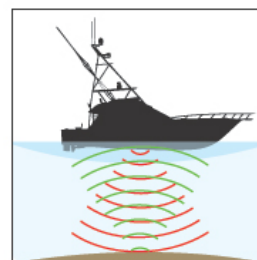## PASCO TRACK

This long metal track is designed to produce very little friction when a cart moves along it. Some features:

- A ruler along the edge, marked in centimeters.
- Two leveling feet on either end, to level the track.
- Two end stops (to prevent the cart from falling off the end of the track)
- An angle indicator attached to the side, giving the angle between the track and the horizontal.

The track can be leveled, as follows:

- Place the level on the track so it is parallel to the length. Adjust the leveling screws so the bubble on the level is in the center.
- Now, place the level on the track so it is perpendicular to the length. Adjust the leveling screws so the bubble on the level is in the center.
- Place one of the carts without wheels in the center of the track on one end, and tip the track. The cart should slide down toward the bumper without sliding to the right or left. If it slides noticeably

PASCO 850 INTERFACE

The 850 interface (shown to the right) accepts input from sensors (we will use photogates, force sensors, ammeters, etc.), and sends the information to the computer. **Capstone**, the application that controls the sensors, tells the interface how to supply power, and accumulates and displays the data. There is an icon on every computer in the physics labs labeled *Shortcut to Lab Files*. If you double click on this icon, you will see a list of lab files:
101 Excel Lab.Cap, 102 Displacement, Velocity, Acceleration Lab.Cap, etc.

If you click on one of these, a pre-written **Capstone** file for your lab will load.

USING CAPSTONE FOR GRAPHS

The display could be a graph (as on the next page) or one or more boxes showing digits (shown to the right).
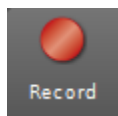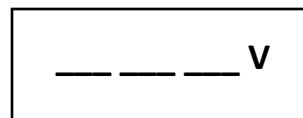
At the bottom of the graph is the *Controls* palette which includes the *Record* icon (shown to the left). If this icon is not red, there is something wrong with the sensors- ask your lab teacher for assistance.

When your click on the *Record* icon:

- the system begins recording data
- the clock starts running
- the *Record* icon becomes the *Stop* icon (shown to the right)
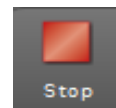
Each time the *Record* icon is pushed, **Capstone** collects data as a *run*, displaying it in real time on the graph or digits box. Each *run* is saved with a number for identification (shown to the right).
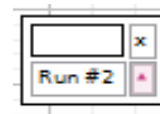
When you click on the *Stop* icon:

- the clock stops running
- the system stops recording data
- the *Stop* icon becomes the *Record* icon again..

The *Delete Last Run* icon (shown to the right) also appears in the *Control* palette, and its function is self-explanatory. But you can also use the down arrow on the icon to access previous runs and delete them all at once. The rest of the *Controls* pallet can be ignored unless someone tells you otherwise
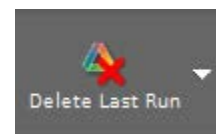
You can collect data from many types of sensors- speed, force, current, etc. The examples we use in this appendix refer to motion graphs, but the information applies to any type of data.

When you use a graph it has a legend, x and y labels and a plot label in the bottom-left corner. You can change the label by clicking on it, and you can change the page title by double clicking it. Below is a sample of the graph created by one run:

First let's look at navigating the graph. If you move your cursor over the plot area, it becomes a hand which lets you pan around the graph window- just click and drag. You can use the wheel on the mouse to zoom the axes in and out, but to zoom them individually: move the cursor over the axis you want to change and use the wheel. There is a toolbar above the graph (see the graph above, and the blow-up of the toolbar below).

This toolbar pops in and out of view quite annoyingly, but you can pin it with the little pushpin icon.

- The first icon, on the far left of the toolbar, is the *Scale Too. You can* click on it to zoom into your data- usually too close for comfort, but it's a good start.
- The second icon from the left lets you select between runs, so you can go back and forth. However, it will only display one run at a time.
- The third icon from the left is the *Data Highlighter* which allows you to select data points, or a subset of your data. Clicking on this icon creates a shaded box over the graph (shown left). There are handles on the edge of the shaded area to resize it and/or move it anywhere in the window. With a part of the graph highlighted, only shaded data will be analyzed. (In the example above right, four data points are

selected.) You can remove a highlighter by selecting it and pressing delete. (This works with most tools of the **Capstone** tools.).

Next are the all-important analysis tools.

- The fourth icon from the left is the *Sigma* tool (icon shown to the right). If you click on this you can find the minimum, maximum, and mean of selected data. In the graph below, the *Sigma* tool causes these values to be displayed (see below).
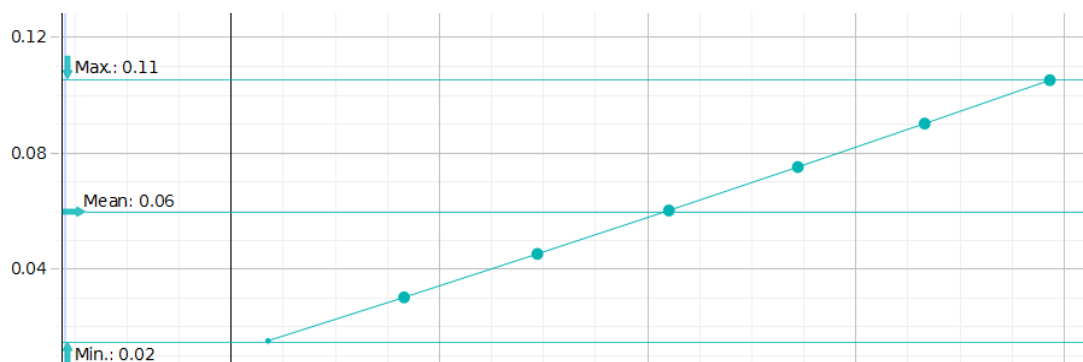
The down arrow on the icon allows you to select which statistics you will display. Deselecting the icon removes the statistics.

- The fifth icon from the left is for the *Area* tool (icon shown to the right). It gives the area between the selected data set and the x-axis (as in the graph to the right). This is useful later in the course.
- The sixth icon, the *Fit* tool, is one of the most useful (icon shown to the right). It allows you to fit your data to a large number of possible types of curves fits, and gives the equation of the best-fit line. In the example to the right, the data is non-linear, and has been fit to a quadratic equation: $Ax^2 + Bx + C$
  As you can see, the fit is very close, as it should be, and the values of the coefficients are given.
- The seventh icon, the *Delta* tool (icon shown to the right), allows you to select a data point and display its coordinates. Click on the icon and drag the widget that appears to your data set. It will grab the nearest data point and report its coordinates. When you let the widget go, it will snap to the closest point. An example of this is shown to the right..

- We will not discuss the other icons on the toolbar, but many are both interesting and useful. The *A* tool (icon shown to the right) allows annotation (comments) be made on the plot.
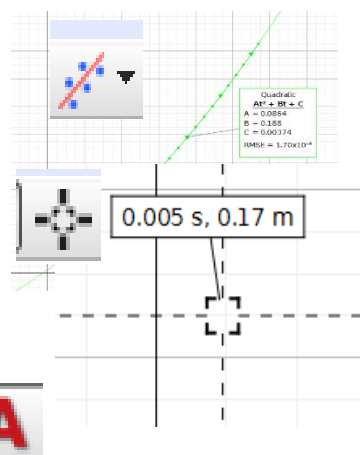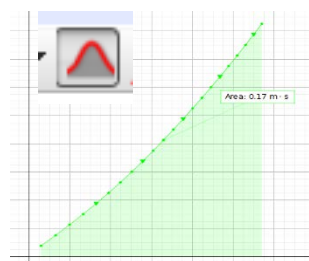
WRITING CAPSTONE FILES

It is possible to write your own **Capstone** file. To start, double click on the icon (shown to the right) to start **Capstone**. The Main window is called a *Workbook*.
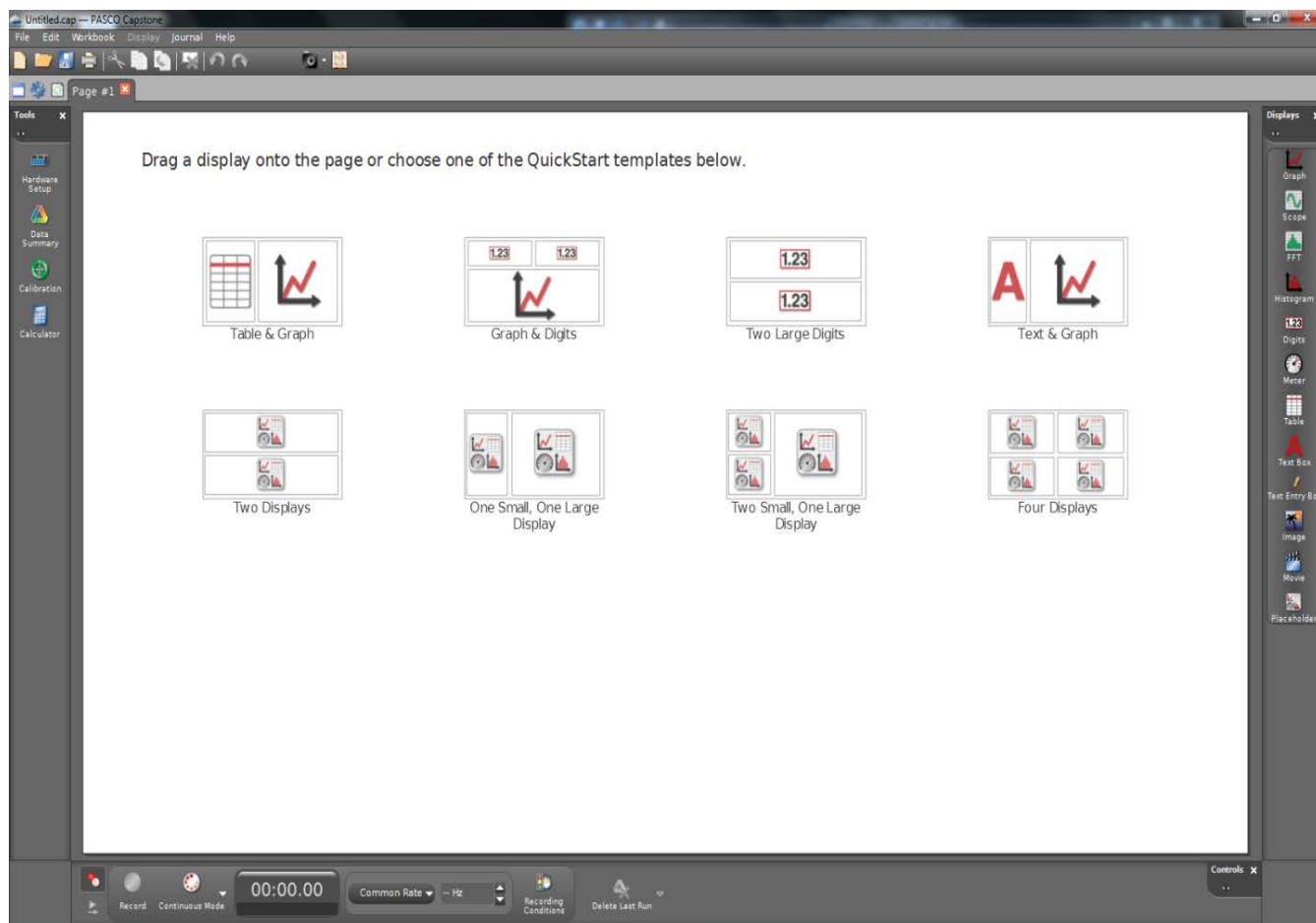
The *Workbook* consists of five palettes and a page which is where data is collected and displayed. At the top of the window are the familiar Windows menus and a tab strip similar to what you would find in any good browser. The most important palettes are *Tools* (see left), *Displays*, and *Controls*, which are arranged around the outside of the data display page. We'll discuss each in turn.

When you come into the lab, there will be an apparatus prepared for you. Look it over to make sure it's correct and the sensors are attached to the 850 interface. Now, you must setup the sensor in **Capstone**. This is done on the Tools palette docked on the left of the workbook. There are five icons in the palette, but the middle three will not be used in the first semester. The *Signal Generator* will be used in the second semester.

First click on the *Hardware Setup* icon at the top, and the set-up window (shown to the right) will slide out. (When the application opens, the icon will flash briefly to remind you.) The image of 850 interface appears with a little light icon in the corner. This is an indicator that the interface is

connected and powered up. If a yellow triangle appears at any time this means there's a problem with the interface. Check the USB connections and the power light on the interface to clear the warning. If the problem persists, ask your instructor.

Once the interface is working correctly you will need to add the sensors. For this example we will add a photogate with a Pulley to measure motion on an Attwood's Machine.


In the *Hardware Setup* window, click on the port where the sensor is connected. In the example the photogate is connected to digital input 1, and the picture shown to the right will appear. Clicking on *Input 1* will open the drop down list for choosing sensors. Select *Photogate with Pulley*. If the sensor is properly installed, the icon will be attached to the interface with a green wire. If not, the wire will be red with a yellow triangle attached. If everything is correct, a new icon will appear in the *Tools* palette. This does not happen with every sensor, but the photogates require a timer. Click on the *Timer Setup* icon.

This sensor records the passing of the spokes of the pulley across the sensor, and **Capstone** uses that raw information to calculate several physical quantities. For this example, we must use position, linear speed, and linear acceleration, so the other options should be deselected. That's all we need to do for the timer, so select save, and click the *Timer Setup* icon to remove the window.

Select the measurements that will be visible (this can also be done in the Data Summary Tool):

- ☐ State
- ☑ Block Count
- ☐ Block-to-Block Times
- ☑ Position
- ☑ Linear Speed
- ☑ Linear Acceleration
- ☑ Angle
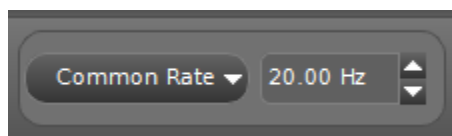- ☑ Angular Speed
- ☑ Angular Acceleration

Next a display is needed. There are several to choose from. Some preconfigured solutions are available in the page window, and sometimes you might need a pair of digit displays- both of these are illustrated in the previous section. However, most often we will use a single graph.
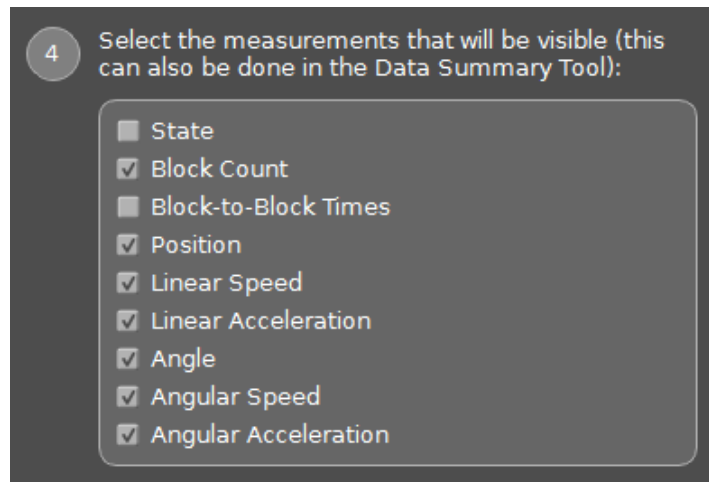
Double click on the *Graph* icon in the *Displays* palette (shown to the right). There are a lot of options in this palette, but you will not be using most of them in this lab course. Double clicking the *Graph* icon fills the page with a single large graph. Alternatively you could drag one or more graphs and position them on the *page*, but for this example a single graph is fine.

Note the axes labels; they must be set to the desired measurement. Select the icon on the y axis and you will get a popup of choices. Select *Position (m)*. This will automatically change the *x* axis to Time (s) which is useful for this example. You could click on another icon and make another selection, or change the units, but this is not necessary for this experiment.

Next we have to configure the sensor. Look at the *Controls* palette. There are several important controls here, to configure the sample rate of the sensor, look at the area in the center. The *Common Rate* (shown to the left) refers to which sensor is being configured, since there is only one sensor *Common Rate* is the default, but if there were several sensors, which will happen later in the course, we could select each one and set the sample rate independently. The spinner, currently set at 20Hz, is the sample rate, or the number of readings per second. The best sample rate depends on the experiment, but in general if your graph looks "choppy" or "spikey", try increasing the sample rate until you get a nice smooth graph. The example is studying accelerated motion which will happen very quickly, so the sample rate should be increased to 50Hz. It can be changed with the spinner arrows.

PHYSICS 121.1
APPENDIX H: DOUBLE PAN BALANCE

DOUBLE PAN BALANCE

The balance is used to measure mass:

- Start with the slide on the front bar all the way the left (at zero). The arrow at the top should point to the center line. If it does not, ask your lab instructor for assistance.
- Place the object to be measured on the **left-hand pan**.
- Place weights on the **right-hand pan** until they almost balance. The weights must be slightly less in mass than the object to be measured.
- Move the slide on the front scale until the arrow at the top is back to zero.
- The total mass is now the mass on the pan plus the reading of the front scale.

ELECTRONIC PROTRACTOR

This device is used to measure the angle between a surface and the horizontal.

A bar is leveled by placing the protractor along its length and adjusting it until the angle reads exactly zero.

A surface has two dimensions. Therefore, to level it, you must use the protractor twice: once along the length of the track and once along the width of the track.

Before using the protractor it must be calibrated. At the start of the lab, bring your protractor to a level place. (Your instructor will tell you which surface is level.) Press the ZERO button to calibrate the protractor. After this: do not touch the ZERO button on the protractor; if you do, you will need to recalibrate it.