Mechanics Module 1
Student Guide

Concepts of this Module

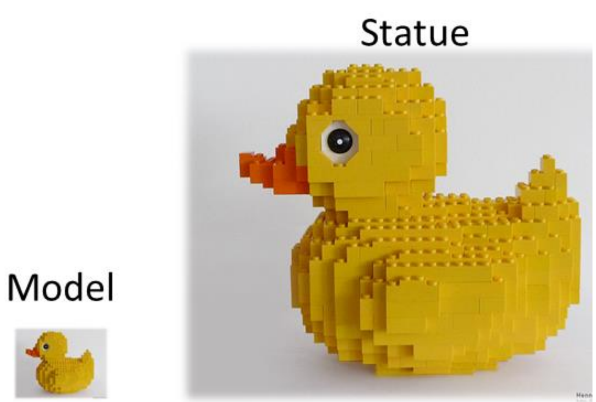
- Scaling
- Dimensions
- Fermi Problems
- Introduction to Experimental Uncertainties
- Kinematics in One Dimension
- Motion Diagrams
- Setting up Newtonian Dynamics

The Activities

Course Concepts *Activity 1*

A sculptor is making a statue of a duck. She first creates a model. To make the model requires exactly 2 kg of bronze. The final statue will be 5 times the size of the model in all three dimensions. How much bronze, in kg, will she require to cast the final statue?

You may find it helpful to think about the model being constructed of Lego blocks, with the final statue made of Lego blocks that are 5 times the size in each dimension as the ones used to make the model.



[Lego Duck image courtesy of Henning Birkeland 2009 http://www.henningb.com]

Activity 2

When the sculptor finished making her model of the duck statue, she gave it 2 coats of varnish. This took exactly one can of varnish. How many cans of varnish will she need to give the final statue 2 coats of varnish?

Activity 3

Surprisingly, the units of all physical quantities can be defined in terms of combinations of only four fundamental units: a unit for length, mass, time, and electric current. In the SI system the units are:

- Second, *s*: the time required for 9,192,631,770 oscillations of the radio wave absorbed by the cesium-133 atom.
- Meter, *m*: the distance traveled by light in a vacuum in 1/299,792,458 of a second.
- Kilogram, *kg*: the mass of the international standard kilogram, a polished platinum-iridium cylinder stored in Paris.
- Ampere, *A*: the constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

Mort the politician has a not-so bright idea that we could save money by simplifying the standards for units. Instead of having a unit of length be fundamental, the politician suggests having a unit of *volume* as fundamental. Of course this unit of volume would be called a *mort*. Then, instead of a difficult to measure and expensive separate standard for length we could define the volume of the standard kilogram to be exactly 1 *mort*.

(a) In this system of units, what is the unit of density?
(b) What is the density of the standard kilogram in *kg*/*mort*?
(c) The density of the standard kilogram is about 21,500 kg/m^3. The density of water is 1.000×10^3 kg/m^3. What is the density of water in *kg*/*mort*?
(d) In this system of units *length* is now a derived quantity. What is its relation to the *mort*?
(e) You have a replica of the standard kilogram and an object of unknown material with a similar volume. How might you actually measure the volume of this object to determine if its volume is greater than, less than, or equal to one mort?

Course Concepts *Activity 4*

The ancient Greeks built a temple to Apollo on the island of Delos. It was 11 m wide, 24 m long, and 10 m high. In 427 B.C. a plague ravaged Athens, and the Athenians consulted the oracle on Delos, who demanded that they double the size of the temple.

(a) What is the original volume of the temple?
(b) The Athenians re-built the temple by doubling the size of each dimension of the temple. What was the volume of the new temple?
(c) The Athenians consulted to oracle again, who said “You have not doubled the size of god’s temple, as he demanded of you.” What mistake did the Athenians make?
(d) What would be the dimensions of the temple that the oracle wanted the Greeks to build?

Course Concepts *Activity 5*

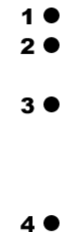
The density of air is approximately 1 kg/m^3. Estimate the mass of the air in this room. This should be an “order of magnitude” estimate, with no more than one significant figure.

Activity 6

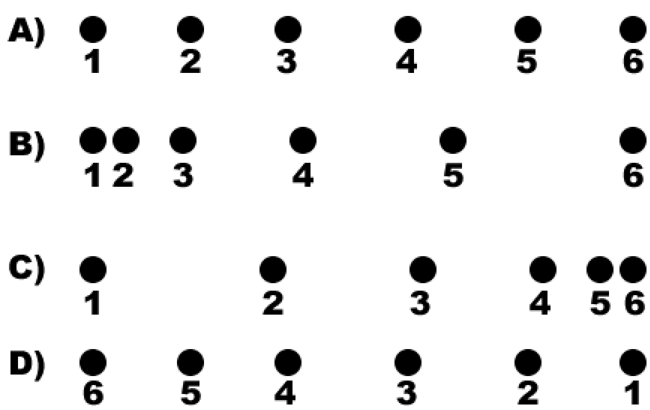
A useful visualization technique in studying motion is called a *motion diagram*. We will be using these diagrams frequently in this course.

For example, consider an apple that is dropped from rest at some height above the ground.

For many objects in translational motion we can ignore the details of the object itself and model the object as an ideal particle and draw it as a simple dot. We number each dot to show the order in which the apple was at the positions indicated. The same amount of time elapses between each dot and the next one. The figure to the right shows the motion diagram for the apple in free fall.



Four motion diagrams are shown below. One is of a car moving to the right at constant speed, one is of a car moving to the left at constant speed, one is a car accelerating to the right away from a stop light that has just turned green, and one is a car moving to the right and slowing down as it approaches a stop sign. Which motion diagram corresponds to which case?



Course Concepts Activity 7

A. If a motion diagram represents the position of an object every second, then the distance between each dot and the next is numerically equal to the average speed of the object during that one second interval. For the motion diagrams of Activity 6, draw a line from each dot to the next representing the magnitudes of these speeds. Put an arrowhead on each line indicating the direction of the motion.
B. Imagine that two of the dots in the motion diagram are separated by 0.15m. If the second dot is the position of the object 1.0 second after the position of dot 1, what is the average speed of the object during this one second interval?
C. Imagine that the two dots of Part B, 0.15 m apart, represent the positions of the objects for a time interval of 0.50 seconds. Now what is the average speed of the object during the half-second interval?
D. In Part A you “connected to dots” of the motion diagram. If the motion diagram represents the position of the object every millisecond, what is the relationship between the length of the line from each dot to the next and the average speed of the object during that millisecond?

Course Concepts Activity 8

Here are some made up data for the x component of the position of an object at various times:

Time (s)	Position (m)
0.00	0.002
0.10	0.111
0.20	0.385
0.30	0.892
0.40	1.613
0.50	2.501
0.60	3.612

A. Sketch a graph of position vs. time. . Make the horizontal axis the time and the vertical axis the position.
B. Is it reasonable to “connect the dots” with a smooth line in the graph you sketched? If yes, what assumption is being made about the motion of the object? If no, why?
C. Sketch a motion diagram of the motion of the object.
D. Calculate the displacements of the object for each 0.1 s interval.
E. How does the number of displacements you calculated compare to the number to the number of data points in the position-time data?

F. From Part D, calculate the x components of the average velocities of the object for each 0.1 s interval.
G. Consider the first of the average velocity values from Part F. At what time does the object have this value of the average speed? Is the value of the time a single value or a range of values? Why?
H. Sketch a graph of the average velocity versus time. Make the time the horizontal axis.
I. From your result from Part F calculate the x component of the average acceleration of the object for each 0.1 s interval. How does the number of calculated values of the average acceleration compare t the number of data points in the position-time data?
J. Sketch a graph of the average acceleration versus time. Make the time the horizontal axis.
K. What does the data indicate about the acceleration of the object?

Expt *Activity 9*

Imagine that the data from Activity 8 were taken with a computerized data acquisition system. The system has nearly perfect accuracy, but the precision of each distance measurement is ± 0.020 m. What are the corresponding uncertainties in the calculated values of the displacements, velocities, and accelerations/

Expt *Activity 10*

An experiment to determine whether Energizer or Duracell batteries last longer could measure the number of hours two AA batteries from each brand will run a tape player. Here is some made up data:

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Average**
Duracell (hours)	11.4	12.2	7.8	5.3	10.3	**9.4**
Energizer (hours)	11.6	7.0	10.6	11.9	9.0	**10.0**

A. From the data, what brand of battery would you choose for your tape player?
B. Why do you think there is such a large variation for the different trials of the same brand of battery?

Preparing for Activities 11 - 13

The next few Activities will involve a Track and Collision Cart. The Track should be leveled, but you should check to make sure.

1. Push the Cart and let it run up and down the Track a few times to warm up the bearings in its wheels.
2. Place the Cart near one end of the Track and give it a very gentle push. It should drift a few centimeters and stop. Give the Cart a very gentle push in the opposite direction: it should drift a few centimeters and stop. If the Cart has a tendency to stop and reverse its direction then the Track needs leveling. The Track may not be perfectly straight, so checking it at both ends can be worthwhile.

The feet under the Track are adjustable by loosening the lock nut and rotating the feet. Be sure to tighten the lock nut when you have the Track level. The Instructors have a level, which may help. The level will be required if you suspect that the Track is not level along the axis perpendicular to its length.

Please do not adjust the positions where the feet are mounted on the Track.

Note that although the Carts have low friction, the fact that they do slow down and stop means the friction is not zero.

At this time, you will find it convenient to measure and record the distance between the feet. The mounts for the feet provide a convenient way to do this. Estimate the position of one of the mounts with the scale mounted on the Track and the corresponding position of the other mount.

You will notice that there is a Cart Launcher mounted on one end of the Track. When the Launcher is used the Track tends to recoil. Thus the bracket for the feet closest to the Launcher is braced with double-rod assembly connected fixed to the tabletop with two table clamps.

You are provided with a set of blocks which will be placed under the feet tilt the Track. There are blocks that are 1.000 cm, 0.500 cm, and 0.100 cm thick. In addition, for one of the Activities you will need finer adjustments than these blocks provide. It turns out that good quality playing cards are carefully controlled in all their dimensions, and are typically 0.029 cm thick. You are provided a deck of playing cards with the card thickness written on the box.

Course Concepts Activity 11

A Cart Launcher is mounted on one end of the Track. Raise the other end of the Track by raising the feet 3.000 cm. The Launcher may be cocked by pulling back the horizontal rod until the disc mounted on it latches to the “finger” on the base. Cock the Launcher and place the Cart against it. Fire the launcher.

You want the Cart to travel almost but not quite all the way up the Track. You want the highest position to be at least a few cm away from the magnetic bumper mounted on the far end of the Track, so the cart does not interact with the bumper. You may need to adjust the Launcher to achieve this. There is a disc mounted on the rod that pushes the Cart whose position can be adjusted to get the desired force.

A. Sketch a motion diagram of the movement of the Cart up the Track from a moment after it leaves the launcher until it comes to rest. It should have some resemblance to one of the motion diagrams of Activity 6.
B. Roughly, what is the time between each successive dot of Part A?

Remember that best laboratory practice is to record *everything*. The Launcher includes a scale that reads how far the spring has been compressed when it is cocked. You should record this value.

Expt Activity 12

This Activity uses the same setup as Activity 11.

Note and record the position of the Cart as measured by the scale on the Track when it is resting against the Launcher when it is not cocked.

A. Launch the Cart and note the position on the scale of the Track where the Cart is at its maximum distance. Repeat a few times, recording each position. Are the values exactly the same for each launch?
B. What are all the reasons you can think of to explain why the positions are not exactly repeatable? The manufacturer of the Launcher says it will launch the cart “with the same force each time.” Is this statement correct?
C. How can you quantitatively characterize the spread in values of the positions that you measured?
D. Is it possible to have an apparatus similar to this one for which the positions would be exactly the same each time?

E. What is the mean, i.e. average, value of the positions you measured? What is the mean value of the total distance the Cart travels up the Track between launch and momentarily coming to rest at the top of the Track?

Course Concepts *Activity 13*

Now raise the feet on the end of the Track opposite the Launcher by 3.500 cm. Measure the distance the Cart travels up the Track. Although you may do a careful measurement like you did in Activity 12, just estimating the position of the Cart at its greatest distance to the nearest centimeter will be sufficient. Remember to keep the end of the Track with the Launcher against the U-shaped rod to minimize rebound.

A. The total distance the Cart travels is less than in Activity 11. So the angle of the Track and the distance the Cart travels are both different. Is anything the same? If so, what?
B. It is unlikely that your answer to Part A came out numerically perfect. What are all the reasons you can think of to account for the small variation from perfection?

This Guide was written in May, 2007 by David M. Harrison, Dept. of Physics, Univ. of Toronto. Activity 10 is from R.L. Kung, Am. J. Phys. **73** (8), 771 – 777 (2005).

Last revision by Jason Harlow: Sep. 12, 2013.