PHY 209
Space and Time in Elementary Physics

Vectors—Part V (an application: Newton's Law of Motion)

Recap

Last time, we practiced drawing some free-body diagrams.
Recall what was involved.

1. *Isolate* the object under consideration.
2. Consider *all* of the forces that are applied *on* the object.
3. Take the *vector-sum* of all of these forces;
   this is called the **net (resultant) force** on the object.
4. If necessary or convenient, this vector-sum could have been carried out component-wise, with respect to a particular choice of axes. This is what was done in Vectors—Part IV.

Realize that some **physical input** was required to "identify all of the forces being applied on the object".

Prelude to The Newton Laws of Motion

Aristotle, an ancient Greek philosopher, thought that every object naturally wanted to "be at rest". In other words, "having constant position" or "having zero velocity" was its natural state of motion. If, however, the object had a nonzero velocity, he considered that as an un-natural state of motion, which was to be attributed to the existence of an unbalanced force. Roughly speaking, Aristotle thought that "the object's *velocity* was proportional to the net-force applied on the object".

Galileo, a Renaissance Italian physicist, challenged Aristotle's view. In his own words,

> *(SALVATIUS:) Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals.*
>
> *Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it.*
>
> *With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin.*

> *The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need to throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction.*
>
> *When you have observed all of these things carefully (though there is no doubt that when the ship is standing still eveything must happen this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that.*
>
> *You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still.*
>
> *In jumping, you will pass on the floor the same spaces as before, nor will you make larger jumps toward the stern than towards the prow even though the ship is moving quite rapidly, despite the fact that during the time that you are in the air the floor under you will be going in a direction opposite to your jump.*
>
> *In throwing something to your companion, you will need no more force to get it to him whether he is in the direction of the bow or the stern, with yourself situated opposite.*
>
> *The droplets will fall as before into the vessel beneath without dropping towards the stern, although while the drops are in the air the ship runs many spans.*
>
> *The fish in the water will swim towards the front of their bowl with no more effort than toward the back, and will go with equal ease to bait placed anywhere around the edges of the bowl.*
>
> *Finally the butterflies and flies will continue their flights indifferently toward every side, nor will it ever happen that they are concentrated toward the stern, as if tired out from keeping up with the course of the ship, from which they will have been separated during long intervals by keeping themselves in the air....*
>
> *(SAGREDUS:) Although it did not occur to me to put these observations to the test when I was voyaging, I am sure that they would take place in the way you describe.*
>
> *In confirmation of this I remember having often found myself in my cabin wondering whether the ship was moving or standing still; and sometimes at a whim which I have supposed it going one way when its motion was the opposite....*

In short, what Galileo observed was that "having constant velocity" (not constant-position) was the object's natural state of motion. He came to this conclusion because he observed that the mechanical laws of physics cannot distinguish between "being at rest" (*i.e.*, "moving with zero, and therefore constant, velocity") and "moving with a nonzero constant velocity". This is called the Galilean principle of Relativity. *This is the forerunner to Einstein's Principle of Relativity. To learn more about this, you can attend the three lectures I will deliver in PHY 105 just after Thanksgiving. You can also consult the following web-page:*

~~http://altair.syr.edu:2024/LIGHTCONE/~~

http://physics.syr.edu/courses/modules/LIGHTCONE/

An object's natural state of motion is known as its inertial motion.

The Newton Laws of Motion

In 1687, Isaac Newton, a English physicist and mathematician, published the details of his study of the motion of objects. His results built upon the work of Galileo and Kepler, who came before him. In Newton's own words, the following are two of **Newton's Laws of Motion**.

LAW OF INERTIA: *A body remains at rest or in uniform (straight line) motion unless acted on by an unbalanced force.* **(In other words, an object has a constant velocity-vector unless acted on by a non-zero net-force.)** Yet another way to say this is that, an object moving inertially has no net-force applied on it. Such an object is sometimes referred to as a "free particle".

$\vec{\mathbf{F}} = \mathbf{m}\vec{\mathbf{a}}$: *A body acted on by an unbalanced force experiences a change from uniform motion proportional to this force.* **(In other words, an object has a non-zero acceleration-vector proportional to a nonzero net-force.)** Recall that a nonzero acceleration means that the velocity is not constant in time.

This "proportionality constant" is called the mass of the object. It is measure of the amount of matter contained the object. This number is positive.

Realize that if two vectors are proportional to each other and the "scaling-factor" is positive, then the vectors point in the same direction. Thus, $\vec{F} = m\vec{a}$ means that "the object accelerates in the direction of the net-force" and that "the force required to attain a certain acceleration is proportional to the mass of the object: larger masses require larger forces."

Falling Objects... Let's Go To The Videotape!

We have brought in a video camera and connected it to a special VCR which can freeze a frame, then advance or back-up a frame at a time, under our control.

We will use this to study the motions of a **dropped object** and of a **thrown object**. Both are examples of **projectiles**.

We want to videotape each projectile in motion. Then, we wish to analyze the videotape to determine if the projectile was accelerating, and, if so, what is its magnitude and its direction?

Using Newton's Law $\vec{F} = m\vec{a}$, we can use this information to determine the direction of the net-force. Furthermore, if we could determine the mass of the projectile, we can calculate the magnitude of the net-force.

⊡ For each projectile, record the positions vs. time for the motion.
Arrange your data in the form of a table.
If the object is dropped, just record height y for each t.
If the object is thrown, record both horizontal distance x and height y for each t.

⊡ On a graph, plot y-vs.-t for the dropped object.
Is there acceleration in the y-direction?

⊡ Based on your data, draw the free-body diagram for the dropped object.

⊡ If there is a nonzero acceleration, use the method I showed you (a while back!) to calculate the average acceleration. Using the given value for the mass m, calculate the magnitude of the net-force F.

⊡ On separate graphs, plot x-vs.-t and y-vs.-t for the thrown object.
Is there acceleration in the x-direction?
Is there acceleration in the y-direction?

⊡ Based on your data, draw the free-body diagram for the thrown object.

⊡ If there is a nonzero acceleration, use the method I showed you (a while back!) to calculate the average acceleration. Using the given value for the mass m, calculate the magnitude of the net-force F.