AST 120 Activity 24
Newton's Laws of Motion

Name	Full	Partial	None

It is probably no exaggeration to say that Isaac Newton's *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy) is the greatest single work ever produced by a human being. It is certainly the greatest work of physics ever produced. In the *Principia*, which was finally published in 1687, Newton ties together the various ideas about celestial and terrestrial motions that had been developed by Kepler, Galileo, and others during the previous century. The result is a small set of principles (three "laws of motion" and one "law of gravity") that can be used to explain and predict an incredible variety of phenomena: the motion of the planets, the motion of the Moon, the fall of objects near Earth, projectile motion, the motion of pendulums, the non-spherical shape of the Earth, the precession of the equinoxes, the tides, and much more that Newton didn't even dream about.

In this activity we will begin exploring Newton's three law of motion. We will begin to see how these laws connect with things we have discussed earlier in the course, but the real payoff will come when we combine these laws with Newton's law of gravity to explain the motion of the planets. That won't come until a later activity, so be patient.

1. We have seen that Galileo introduced the idea of neutral motions. In particular he stated that an object moving along a horizontal surface will keep moving at a constant speed unless something interferes with it. But we also saw that for Galileo this horizontal motion was actually motion in a circle centered on the Earth's center. This idea was amended in the 1640s by French natural philosophers Pierre Gassendi and Reneé Descartes. Newton would take Gassendi and Descartes' *principle of inertia* as his first law of motion:

   > Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by forces impressed.

   This implies that the only natural kind of motion is ______________.

   (a) free fall
   (b) motion in a straight line at constant speed
   (c) motion in a circle at constant speed
   (d) motion toward the Sun

2. For Galileo, falling motion was natural, horizontal motion was neutral, and other motions were violent. But for Newton we see that he must treat the fall of an object as a ______________ motion.

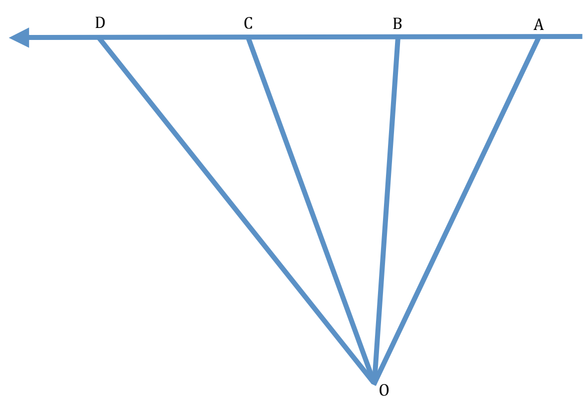
   (a) natural
   (b) neutral
   (c) violent
   (d) impossible

3. If we accept Newton's first law, then the fall of an object must be due to ______________.
   (a) the object's natural tendency to move toward the center of the Universe
   (b) the object's affinity for other Earth-like things
   (c) a force impressed on the object
   (d) the object's natural tendency to flee from the stars

4. Consider the following situations. In which of these situations is the object being "compelled to change its state by forces impressed?" Circle all correct responses.
   (a) an object sits at rest on a table
   (b) an object rolls at constant speed along a horizontal plane
   (c) an object rolls along a horizontal plane but slows down as it rolls
   (d) an object moves in a circle at a constant speed

5. Another way to state Newton's first law is that an object will maintain a constant *velocity* unless the object is acted on a by a force which changes the object's velocity. Velocity is a quantity that combines two familiar things: the speed at which an object is moving (instantaneous speed) and the direction of the object's motion. If *either* of these two things changes, then the velocity has changed and therefore the object must have been acted on by a force. In which of the following cases does the velocity of the object change? Circle all correct answers.
   (a) a racquetball hits a wall and bounces straight back with the same speed
   (b) a bicycle rides along a straight and level trail at a constant speed
   (c) a car makes a right turn while maintaining a constant speed
   (d) a car drives down a straight road while speeding up
   (e) an object sits at rest on a table

6. Now let's look at an interesting feature of motion with constant velocity (or *inertial* motion). The diagram below shows an object moving at a constant speed along a straight line (indicated by the arrow). At time $t = 0$ the object is at A, at $t = T$ the object is at B, at $t = 2T$ it is at C, and at $t = 3T$ it is at D.



   How do the lengths of the line segments $\bar{AB}$, $\bar{BC}$, and $\bar{CD}$ compare?

7. How do the areas of the triangles OAB, OBC, and OCD compare?

8. In what way is this result related to Kepler's Second Law of planetary motion?

9. OK, so now we know an object is supposed to move in a straight line at constant speed unless forces are impressed on it. But what if forces *are* impressed on it? Then what does it do? That's where Newton's second law comes in:

   > A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed.

   By "change in motion" Newton means what we would now call *acceleration*.[1] We have already encountered the idea of acceleration in Galileo's study of free fall. But here acceleration means *any change in motion*. If the object changes speed, that's an acceleration. If an object changes the direction it is moving, that's also an acceleration. Which of the following objects is accelerating? Circle all correct answers.

   (a) an object sits at rest on a table
   (b) an object rolls at constant speed along a horizontal plane
   (c) an object rolls along a horizontal plane but slows down as it rolls
   (d) an object moves in a circle at a constant speed

10. Does an object in free fall accelerate? If so, in what direction is its acceleration?

11. Now, Newton's second law indicates that the acceleration experienced by an object is proportional to the force on the object. We can express this as $a \propto F$, where a is the acceleration and F is the force. Suppose we have a block sitting on a frictionless surface (maybe really slick ice?). If we push on this block in a horizontal direction with a force F_1 the block will experience an acceleration a_1. Now, if we were to push on the same block with a force $4F_1$ what acceleration would the block experience?

    (a) $a_1/4$
    (b) $a_1/2$
    (c) a_1
    (d) $2a_1$
    (e) $4a_1$

12. If $a \propto F$, this implies that if we divide the force F by the acceleration a we will find that F/a for a particular object is______________.

    (a) always the same
    (b) larger whenever F is larger
    (c) larger whenever F is smaller
    (d) larger whenever a is smaller

[1] Actually Newton means a change in what we now call *momentum*, but for convenience we will make use of the idea of acceleration instead.

13. Suppose the block mentioned above was a block of wood. Now we get another block of wood that has a volume twice as great as the first block. When we push on this new block with our force F_1 we find that the new block has an acceleration $a_1/2$. So if we calculate the ratio F/a for this new block we find that it is ______________ as the ratio for the original block.

    (a) half as great
    (b) the same
    (c) twice as great
    (d) four times as great

14. The ratio F/a is proportional to the volume of the object. But it can't *just* be related to volume, because if we used a block of lead with a volume equal to the volume of our original block of wood we would get a different (and much larger) value for F/a. To quantify this ratio we will define a new quantity called *mass*. The mass m of an object is just the ratio of any force applied to that object to the acceleration that object will experience: $m = F/a$. Looking at this relationship we can say that the mass of an object measures that object's ______________.

    (a) resistance to motion
    (b) resistance to changes in motion
    (c) propensity for motion
    (d) propensity for changes in motion

15. If we apply a force F_1 to an object with mass m_1 it experiences acceleration a_1. What acceleration will be experienced by an object with mass $2m_1$ subject to the same force?

    (a) $a_1/4$
    (b) $a_1/2$
    (c) $2a_1$
    (d) $4a_1$

16. Note that we can rewrite Newton's second law as $F = ma$. This is how it is usually presented in textbooks (although Newton never wrote it this way - in fact, he didn't use equations at all). Let's try to understand how all these quantities fit together. Again let's take the example of applying a force F_1 to a block with mass m_1 and it experiences an acceleration a_1. If we apply a force $5F_1$ to a block with mass $3m_1$, what acceleration will this block experience?

17. Newton made a big deal about stating that the acceleration experienced by an object is in the same direction as the force acting on the object. Notice that we now have a totally new view about the direction of forces. In Aristotle's physics the force is always in the direction of the object's motion (so it is in the same direction as the object's *velocity*). We already saw this start to break down with Galileo who showed that an object can move horizontally even when there is no horizontal force. Newton completes the divorce between force and velocity. In Newton's second law the two are totally independent, so we can have lots of different combinations of force and velocity (whereas for Aristotle there was a one-to-one correspondence since the force basically determined the velocity). Let's think of a few examples and see if you can determine what will happen in each case. Suppose a block is sliding on some ice and we push the block in the direction it is moving. The block will ______________.

    (a) slow down
    (b) speed up
    (c) turn left
    (d) turn right

18. Suppose a block is sliding on some ice and we push the block in a direction opposite to the direction it is moving. The block will ______________.

    (a) slow down
    (b) speed up
    (c) turn left
    (d) turn right

19. Suppose a block is sliding on some ice and we push on the block toward the right (from the perspective of someone facing in the direction the block is moving). The block will ______________.

    (a) slow down
    (b) speed up
    (c) turn left
    (d) turn right

20. What is the direction of the force on an object in free fall? Be as specific as possible (i.e. tell me exactly toward what point this force is directed). What object do you suppose is responsible for the force on a body in free fall?

21. Using Newton's first two laws we can now understand how an object moves when it is subject to a constant force.[2] Newton makes it clear in the *Principia* that the motion of an object subject to a constant force is just the motion the object would have had without any force (in a straight line at constant speed) *plus* the accelerated motion that is due solely to the force. When we add these two motions we must be careful to account for the distance AND the directions. Here's how Newton says it in Corollary 1 of the *Principia*:

    > A body acted on by [two] forces acting jointly describes the diagonal of a parallelogram in the same time in which it would describe the sides if the forces were acting separately.

    To see how Newton's idea applies to the case of projectile motion, run the `ProjectileMotionGalileoNewton` program. In the View menu, select Newton's View. In the Options menu, select Show Lines. The animation shows a projectile (in magenta) as well as the motion the projectile would have if it was not affected by gravity (blue) and the motion it would have if it had no initial speed (the red ball). You can see that the motion of the projectile is just a combination of two motions. The movement of the ball due to its inertial motion is shown by the ______________ line while the movement of the ball due solely to the effects of gravity is shown by the ______________ line.

    (a) red ... blue
    (b) magenta ... red
    (c) blue ... red
    (d) blue ... magenta

[2] Changing forces are harder to deal with. They generally require calculus, which is beyond the scope of this course. But we will explore a few specific examples of changing forces a bit later.

22. So far this looks just like Galileo's explanation of projectile motion: vertical motion at constant acceleration coupled with horizontal motion at constant velocity. But Newton's view, although equivalent to Galileo's, is somewhat different in perspective. Newton takes the natural motion of the projectile to be whatever motion it started with, whether that motion is horizontal or vertical. Deviations from that natural motion occur only because of the action of a gravitational force. So Newton breaks up the motion differently. Set the launch angle in the simulation to 45° and set the initial speed to 50 m/s. Make sure your values have been properly entered (no yellow in the boxes) then click Play. As you watch the animation you should see a parallelogram form. The ______________ of this parallelogram shows the motion of the object due to its natural inertial motion (remember that it was initially launched at a 45° angle above horizontal) and the ______________ of the parallelogram shows the motion of the object due to gravity only. Make sure you understand how this picture fits with Newton's Corollary 1 given above.

    (a) top . . . left side
    (b) top . . . bottom
    (c) right side . . . left side
    (d) left side . . . top

23. Now let's introduce Newton's third law:

    > To any action there is always an opposite and equal reaction; in other words, the actions of two bodies upon each other are always equal and always opposite in direction.

    Another way to state this is that if object A exerts a force on object B, then object B also exerts a force on object A. These two forces are equally strong (technically we say they have the same *magnitude*), but point in opposite directions. Let's try applying this idea. Suppose you push on a wall with a force of magnitude F. Your push is directed horizontally to the East. The wall ______________.

    (a) pushes back on you with a force of magnitude F directed due East
    (b) pushes back on you with a force of magnitude F directed due West
    (c) pushes back on you with a force of magnitude less than F directed due West
    (d) pushes back on you with a force of magnitude greater than F directed due East
    (e) does not exert any force on you

24. If a tank crashes into a Mini Cooper, the tank exerts a force on the Mini and the Mini ______________ on the tank.

    (a) exerts a smaller force
    (b) exerts a force of equal magnitude
    (c) exerts a larger force
    (d) does not exert any force

25. Which vehicle (the tank or the Mini) would experience a greater acceleration? Why?

26. Based on the consideration in this activity we now know that gravity is a force that the Earth exerts on nearby objects. This force is what you usually call the *weight* of an object. So the Earth exerts a force on you that is just your weight. Do you exert any force on the Earth? If so, how does the magnitude of this force compare to your weight? How does the Earth's acceleration as a result of this force compare to your acceleration as a result of your weight?