AP Physics - Unit 2 - Dynamics

NATIONAL
MATH + SCIENCE
INITIATIVE

AP PHYSICS 1

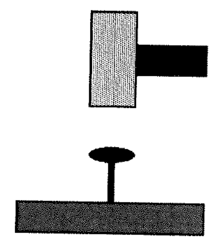
wkst: Forces on a System of Objects # 3

Pre-Assessment Questions

The "action" and "reaction" of Newton's Third Law represent two forces that act at the same time. Since they act at the same time, they cannot be "cause" and "effect". In fact, "action" and "reaction" are "cause and cause"; the two effects are the resulting motions or changes in motion of the two objects acting on each other. In the boxes below, fill in the blanks to correctly represent the "action" cause-and-effect and "reaction" cause-and-effect that take place in the situation described. The first one has been done for you.

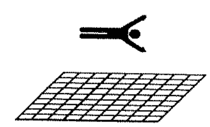
P1.	Cause	Effect
"Action"	The hammer pushes down on the nail.	The nail moves downward into the board.
"Reaction"	The nail pushes up on the hammer.	The hammer bounces off of the nail.

Situation: A hammer strikes a nail.



P2.	Cause	Effect
"Action"	The person ________ ("pushes" or "pulls") ________ (direction) on the net.	The net bows downward.
"Reaction"	The net ________ ("pushes" or "pulls") ________ (direction) on the person.	The person ________ ________.

Situation: A falling person lands in a net.



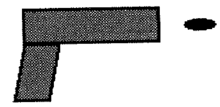
P3.	Cause	Effect
"Action"	The ________ (object) ________ ("pushes" or "pulls") ________ (direction) on the ________ (object).	The air flows downward.
"Reaction"	The ________ (object) ________ ("pushes" or "pulls") ________ (direction) on the ________ (object).	The airplane stays at the same height.

Situation: An airplane flies without falling or rising because it interacts with the air.

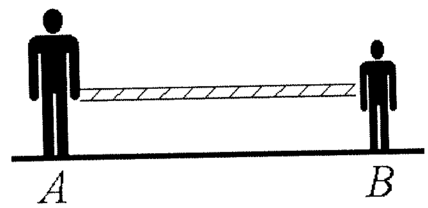
P4.

	Cause	Effect
"Action"		
"Reaction"		

Situation: A gun fires a bullet.

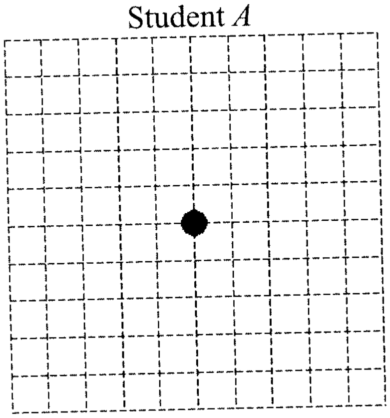


P5. Student A is much heavier and stronger than Student B. Both students engage in a tug-of-war match, and Student A wins. Student C, observing this, says "Student A won because he pulled on the rope with more force." This is incorrect.

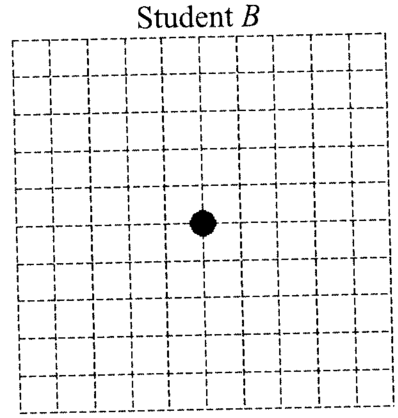


(a) Draw free-body diagrams showing the weight, normal, friction, and tension forces on each student. Use the grid so that longer arrows can represent stronger forces.

Student A



Student B



(b) Correct the student's statement about who pulled harder on the rope, and use your FBDs to explain what actually causes Student A to win the tug-of-war. (Hint: B could win the tug-of-war of A were standing on a wet tile floor.)

Newton's first and second laws deal with the forces acting on a single object:

- **Newton's First Law** – An object moves with constant velocity if and only if all of the forces acting on the object balance, adding to zero.
- **Newton's Second Law** – If the forces on an object do NOT add to zero, there is a net force and the object accelerates. This acceleration is directly proportional to the net force and inversely proportional to the object's mass.

Every force that occurs consists of the interaction between two things. The thing being forced is called the "object" of the force and the thing doing the forcing is called the "agent". **Newton's Third Law (N-3)** deals with the fact that both the object and the agent have forces acting on them at the same time:

Wrong: "For every action there is an equal but opposite reaction." (NEVER say this.)
Right: **"If *A* exerts a force on *B*, then *B* exerts a force on *A* that is equal in strength and opposite in direction."**

Why "wrong" is *WRONG*: What is "action" and "reaction", anyway? This way of saying N-3 doesn't even hint that we are talking about forces. Also, the wrong way of saying N-3 makes a person think that "action" and "reaction" are cause-and-effect (they are not).

Some Notes on Newton's Third Law:

- *A* exerts a force on *B* and *B* exerts a force on *A*. One of those forces is called the "action" force and one is called the "reaction" force. It doesn't matter which is "action" and which is "reaction". Together they are referred to as an "action/reaction pair."
- The "action" and "reaction" forces act *at the same time, for the same time*. Both forces have the same strength and opposite directions at the same time.
- Because both forces act at the same time, they cannot be "cause" and "effect". ***Both forces are a cause***. The "effect" is the resulting change in motion of the objects the two forces act on.
- The two forces act on different objects every time. Action/reaction pairs never act on the same object.
- Action/reaction pairs can never cancel out. Only two forces on the same object can cancel out, but action/reaction forces never act on the same object.
- Action/reaction pairs are always both the same type of force. If "action" is a normal force, "reaction" is also a normal force. If "action" is friction, so is "reaction", etc.
- Action/reaction pairs are both "push" or both "pull". You will never see a situation where action is "pull" but reaction is "push".

If several objects are treated together at the same time, then we analyze the objects as a **system**. We would consider a system in cases when several objects are connected together (by strings, for example) so that they move together with the same speed or acceleration. When dealing with a system of objects, we classify forces acting on the objects as either "internal to the system" or "external to the system":

- A force is **internal to the system** (an **internal force**) if the object of the force is one of the objects of the system, and the agent exerting the force is *also within the system.*
- A force is **external to the system** (an **external force**) if the object of the force is one of the objects of the system, and the agent exerting the force is *not part of the system.*

Internal forces "connect the system together", but internal forces *cannot speed up or slow down the system.* **Only external forces can change the motion of a system of objects.**

When dealing with a system of objects, we can re-write Newton's Second Law to express the relationship between the external forces acting on the system and the acceleration of the system:

<u>Newton's Second Law for a Single Object</u>

$$\begin{pmatrix}\text{The total of all of the}\\ \text{forces trying to make}\\ \text{the object speed up}\end{pmatrix}-\begin{pmatrix}\text{The total of all of the}\\ \text{forces trying to make}\\ \text{the object slow down}\end{pmatrix}=\begin{pmatrix}\text{the}\\ \text{object's}\\ \text{mass}\end{pmatrix}\begin{pmatrix}\text{the}\\ \text{object's}\\ \text{acceleration}\end{pmatrix}$$

<u>Newton's Second Law for a System of Objects</u>

$$\begin{pmatrix}\text{The total of all of the}\\ \text{forces trying to make}\\ \text{the SYSTEM speed up}\end{pmatrix}-\begin{pmatrix}\text{The total of all of the}\\ \text{forces trying to make}\\ \text{the SYSTEM slow down}\end{pmatrix}=\begin{pmatrix}\text{the TOTAL}\\ \text{SYSTEM}\\ \text{mass}\end{pmatrix}\begin{pmatrix}\text{the}\\ \text{SYSTEM's}\\ \text{acceleration}\end{pmatrix}$$

Center of Mass

A system of objects has a special location which is called the system's **center of mass (CM)**. A single object also has a center of mass, because a single object is actually a system of objects called "atoms".

If the system consists only of two objects, then the CM is on the line joining the two objects and is somewhere between the two objects closer to the more-massive object. If the two objects had masses M and $2M$, then the $2M$ object would be half as far from the system's CM as the M object.

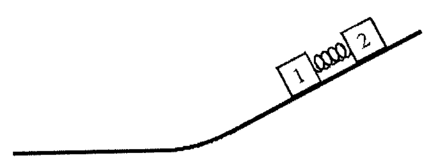
If any of the objects in a system move, then the center of mass *could be* moving. If the CM moves, then we can define a **velocity of the center of mass**. The velocity of the center of mass of a system is the total momentum of the system divided by the total mass. Remember that momentum is a vector, so two objects moving in opposite directions will have opposite-sign momentum, and it is possible for those opposite momentums to cancel to zero.

$$\text{the velocity of the system's center of mass}=\frac{\text{the total momentum of the system}}{\text{the total mass of the system}}$$

If any of the object in a system accelerate, then the center of mass *could be* accelerating. The only way to accelerate a system's center of mass is through the action of **external forces** acting on the system. Only external forces (those forces whose agents are not part of the system) can change the motion of the system's center of mass.

$$\text{the acceleration of the system's center of mass}=\frac{\text{the net external force on the system}}{\text{the total mass of the system}}$$

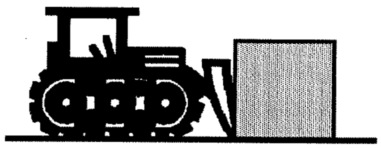
Example: The diagram shows blocks 1 and 2 connected by a spring. Both blocks are made of magnetized iron. They are released from rest on an aluminum ramp and slide down the incline. (Hint: Magnets exert force on each other, and aluminum exerts a force on *moving* magnets.)



The external forces that can change the motion of the system's CM are: weight (comes from Earth), normal, friction, and the magnetic interaction with the track (all three come from the track).

The internal forces that cannot change the motion of the system's CM are: the magnetic force each magnet exerts on each other, and the force of the spring between the magnets.

Multiple-Choice Questions



M1. A heavy tractor force F_T to push a lighter box. Under which conditions will F_B, the force with which the box pushes on the tractor, be equal in magnitude to F_T?

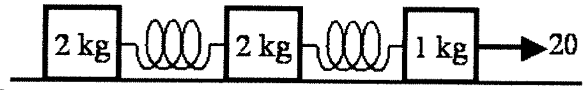
(A) The tractor and box must be at rest.
(B) The tractor and box must be moving with constant velocity.
(C) The tractor and box must be either at rest or moving with constant velocity.
(D) These two forces are always equal in magnitude under all conditions.

M2. Which of the following best explains what a person does in order to jump vertically into the air?

(A) The person uses her legs to push herself up off of the ground with a force equal to her weight.
(B) The person pushes down on the floor with a force equal to her weight, causing the floor to exert an upward force on the person equal to her weight.
(C) The person uses her legs to push herself up off of the ground with a force greater than her weight.
(D) The person pushes down on the floor with a force greater than her weight, causing the floor to exert an upward force on the person greater than her weight.

Skip - Later Chapter

Questions 3–4: Three blocks set at rest on a frictionless surface are connected by identical springs. The rightmost block is acted upon by a constant 20 N force, as shown below, starting at time $t = 0$. The blocks no longer oscillate after 10 seconds.



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M3. Which of the following will be true after 10 seconds have elapsed?

(A) The right spring will be stretched twice as far as the left spring.
(B) The left spring will be stretched twice as far as the right spring.
(C) The right spring will store twice as much potential energy as the left spring.
(D) The left spring will store twice as much potential energy as the right spring.

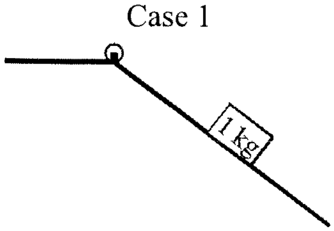
Skip

M4. What is the speed of the center of mass of the system at $t = 2$ seconds, while the blocks are still oscillating?

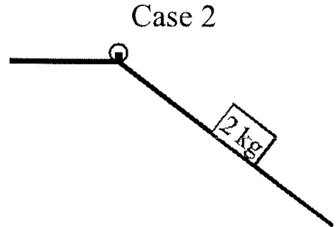
(A) 2 m/s
(B) 8 m/s
(C) 10 m/s
(D) 20 m/s

Questions 5-6: The diagrams below show three cases in which one or more blocks are set on a frictionless track. The frictionless track has straight and inclined sections separated by a pulley wheel. In Case 1, a 1 kg block is set at rest on the inclined section and has an acceleration of 6 m/s^2 upon being released.

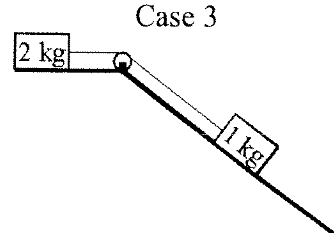
Case 1



Case 2



Case 3



M5. In Case 2, a 2 kg block is set on the inclined section and released from rest. What acceleration will the 2 kg block have as it slides down the incline?

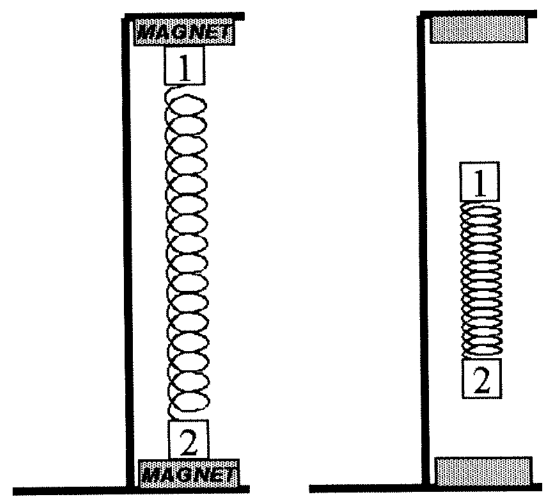
(A) $1\ m/s^2$ (C) $3\ m/s^2$
(B) $2\ m/s^2$ (D) $6\ m/s^2$

M6. In Case 3, the 2 kg block is connected to the 1 kg block by a string. The 2 kg block rests on the horizontal section, the 1 kg block is held fixed on the inclined section, and the string passes over the ideal pulley. What acceleration will the system of blocks have the instant that the 1 kg block is released?

(A) $1\ m/s^2$ (C) $3\ m/s^2$
(B) $2\ m/s^2$ (D) $6\ m/s^2$

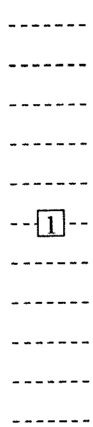
<u>Free-Response Questions</u> F1 - Question Relies on one or more representations

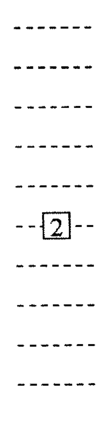
F1. A system consists of two identical steel cubes 1 and 2. The cubes are connected by a strong spring. The diagram shows each cube stuck to an electromagnet and held so that the spring is stretched several times its natural length. At time $t = 0$, both electromagnets are turned off, and immediately both cubes lose contact with their respective magnets.



Before $t = 0$ After $t = 0$

(a) The boxes below represent the two cubes immediately after both cubes lose contact with their respective magnets. On each box, draw and label the forces (NOT components) acting on each cube at this instant. Use the dashed lines to draw arrows whose lengths reflect the relative magnitudes of the forces.





(b) After time $t = 0$, is the system in free-fall? If so, what is accelerating at $9.8\ m/s^2$? If not, why not?

(c) Suppose instead that at time $t = 0$ the magnet for cube 1 turned off but not the magnet for cube 2. Would the downward acceleration of cube 1 be greater, lesser, or the same as the acceleration of cube 1 in the original case? Justify your answer.

F2 - Lab related question

F2. A student is tasked with experimentally demonstrating Newton's Third Law. The student has the following equipment. Note that the student has no equipment to directly measure force.

___ Wooden blocks of different sizes and masses ___ Different metal masses and mass hangers
___ Carts that can hold masses or blocks ___ Video camera with video analysis software
___ Meterstick ___ Stopwatch ___ Motion Sensor ___ Triple-Beam Balance
___ String ___ Springs ___ Rubber Bands ___ Elastic Cord

(a) Mark the space next to each piece of equipment the student should use to make measurements.

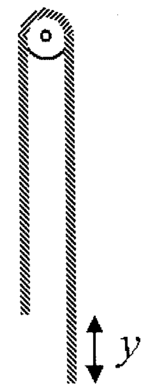
(b) In the space below, outline a procedure whereby the student could use the checked pieces of equipment to make measurements necessary to show evidence of Newton's Third Law. Include a labeled diagram.

(c) Explain how the student would analyze the data. How would the measurements made be used to show Newton's Third Law?

(d) Could the experimental setup in part (b) also be used to show evidence of the Law of Conservation of Momentum? If so, explain how. If not, why not?

F3 - qualitative - quantitative translation

F3. A heavy rope is set over a small, ideal pulley so that one end is a distance y higher than the other, as shown in the diagram. The rope has total length L and a mass-to-length ratio of μ (which would be measured in kilograms per meter). Suppose that the rope is released from rest in this configuration.



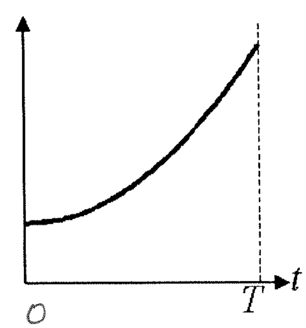
(a) Write expressions for the following in terms of L, y, μ, and fundamental constants.

i. The total mass of the rope

ii. The mass of the piece of the rope of length y

iii. The acceleration of the rope at the moment the rope is released, as a function of y

(b) Let v represent the speed of one end of the rope and a represent the magnitude of the acceleration of one end of the rope. The rope is released at time $t = 0$ and the left end of the rope reaches the pulley at time $t = T$. Three students examine the graph shown to the right and offer the following statements:



Student A: "That graph could represent the length y as a function of time."
Student B: "That graph could represent the speed v as a function of time."
Student C: "That graph could represent the acceleration a as a function of time."

i. Which student(s) is/are correct? Mark the blank next to each correct student.

_____ Student A _____ Student B _____ Student C

ii. In a well-organized paragraph, explain why each correct student is correct, and what is wrong with the wrong students' statements.