

**Question:**

The physics quantity *Work* can be calculated by considering

- a. how quickly a moving object changes its position
- b. how much Force is applied to an object, and how much time that Force is applied
- c. how much an object accelerates, divided by its mass
- d. how much Force is applied to an object, and how much displacement that Force is applied over
- e. how quickly a moving object changes its acceleration

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**Answer:**

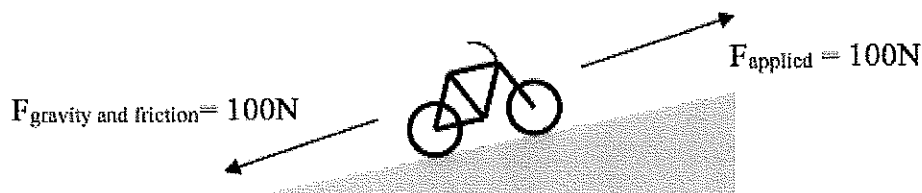
The correct answer is *d*. By definition, the amount of *Work* done on an object is calculated according to the formula *Work = Force • displacement*, or  $W = Fd$ .

There are two “tricks” to *Work* that you need to understand right away.

First of all, the word *Work* in Physics is different from how the word *work* is commonly used in English. Physics *Work* has a specific definition, and is used along with the concept of *energy* to better understand how the world works. If I say “I’m doing *Work* on the chair,” means something very specific to a physics student, as opposed to, say, “I have a lot of *work* to do tonight.” The two words are used in very different ways to mean very different things.

Second, when calculating *Work*, one needs to be sure to use the Force applied *in a direction* multiplied by the displacement that the object moves *in the same direction*. In Conceptual Physics we typically don’t dig very far into this idea because the idea leads to some pretty tricky math that you probably aren’t ready for just yet.

**Question:**



A student applies a constant force of 100 N while pushing a bicycle up a hill, while gravity and wheel friction cause a constant 100 N force in the opposite direction. In this situation

- the student-applied force of 100 N means the bicycle must be accelerating.
- the net force on the bicycle is 0 N, which means the bicycle is not accelerating.
- the combined forces of gravity and wheel friction mean the bicycle must be decelerating.
- the student is not doing any Work on the bicycle as she pushes it up the hill.
- the bicycle can't be moving up the hill because the forces on it are balanced.

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**Answer:**

The correct answer is *b*. The net force on the bicycle is 0, so with no net external force, the bicycle will continue in straight-line motion at constant speed—it will not be accelerating.

Note that *e* is not a correct answer. Although an initial force from the student of greater than 100 N may have been necessary to get the bicycle moving from a standstill, once it is moving (as it is in this problem), the student only needs to apply 100 N of force to keep it moving. If the student applies more than 100 N, the bike will begin to accelerate up the hill, and if the student applies less than 100 N, the bike will begin to slow down.

You may not yet know about the concept of Work, which is mentioned in answer *d*. Work occurs when something applies a Force along some distance. In this case, the student is doing Work as she pushes the bike up the hill, which results in an increase in the bicycle's gravitational potential energy. If you don't know about these concepts yet, you will soon!

**Question:**

A bucket of water with a total weight of 50 Newtons is lifted at constant velocity up a 10 meter deep well. If it takes 20 seconds to raise the bucket this distance, the Work done by the lifting force is:

- a. 25 W
- b. 25 J
- c. 0 J
- d. 50 J
- e. 500 J

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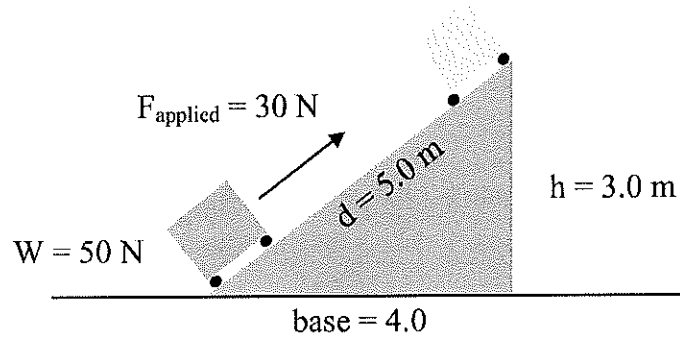
**Answer:**

The correct answer is e. Work done by a Force on an object is calculated according to the Work formula  $W=F \cdot x$ , or  $W=Fx \cos \theta$ . In this case:

$$W = F \cdot x$$

$$W = 50N \cdot 10m = 500J$$

**Question:**



A small cart with frictionless wheels has a weight of 50 N. A student uses a Force of 30 N to roll the cart up the ramp shown above. How much Work was done by the student in moving the cart to the top of the ramp?

- a. 90 J
- b. 150 J
- c. 250 J
- d. 120 J
- e. 200 J

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**Answer:**

The correct answer is *b*. The student applied a force of 30 N while moving the cart in the direction of that force 5.0m. Therefore:

$$W = Fd$$

$$W = (30N)(5.0m)$$

$$W = 150J$$

Notice that this value is the same as the amount of GPE the cart has as it's sitting 3.0 meters above the ground:

$$GPE = mgh$$

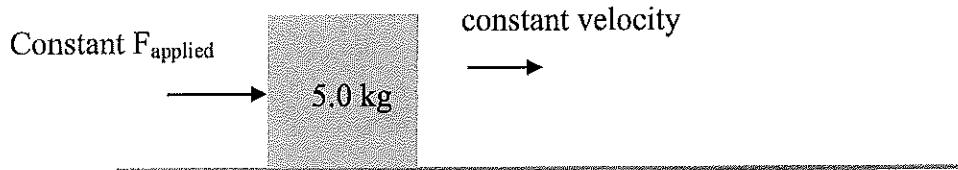
$$GPE = (mg)h = Wh$$

$$GPE = (50N)(3.0m)$$

$$GPE = 150J$$

There's an important lesson here: we do the same amount of Work when raising the box to that height above the ground, whether we lift it straight up or roll it up a ramp. One of the reasons we like to use ramps, though, is that *less force* is required—30 N here applied over a longer distance, instead of 50 N to lift straight up a shorter distance. Either way, the same amount of Work gets done, and the box has the same amount of gravitational potential energy based on the Work that we've done.

**Question:**



A 5.0 kg box resting on the floor is pushed with a constant horizontal force  $F_{\text{applied}}$ , and the box moves to the right with a constant velocity. Which statement below is *false*?

- The net horizontal force on the box is zero.
- There are forces acting in the vertical direction.
- The magnitude of the force applied must equal the magnitude of the force of friction.
- There is net Work being done on the box.
- There is a friction force acting on the floor to the right.

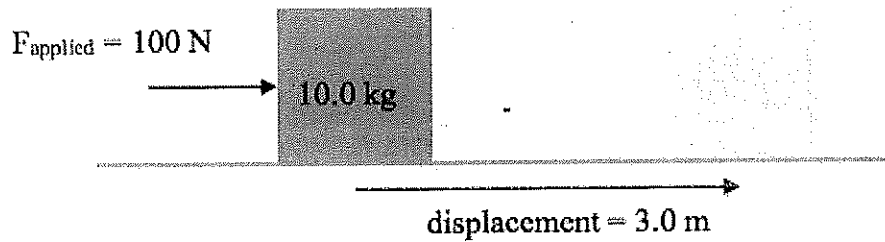
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**Answer:**

The correct answer is *d*. There is no net Work being done on the box because there are no net Forces acting on the box. Another clue that there is no net Work being done is the fact that the box's kinetic energy KE is constant (because it's moving at constant velocity).

While it's true that the  $F_{\text{applied}}$  is doing Work, the force of friction between the box and the floor is doing Work on the box as well, and "losing energy" via heat in the process.

**Question:**



A student uses a horizontal force of 100 N to push a 10.0 kg box across the floor for a total distance of 3.0 meters. The work done on the box by the student is

- a. 1000 Joules
- b. 300 Joules
- c. 30 Joules
- d. 10 Joules
- e. You can't tell without knowing if there was friction in this problem.

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**Answer:**

The correct answer is *b*. The Work done on the box by the student can be calculated by multiplying the Force applied on the box and the distance the box moved in the direction the Force was applied.

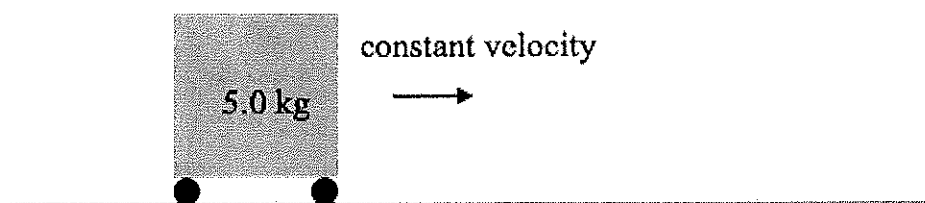
$$W = Fd$$

$$W = (100\text{N})(3.0\text{m})$$

$$W = 300\text{J}$$

It's true that we don't know if there was any friction in this problem, so there are a few things about the box's motion that we can't yet figure out, like the box's acceleration or final velocity. But we *are* able to figure out how much Work the student is doing on the box—how much *energy* the student is transferring to the box—and that's what we've calculated here.

## Question:



A set of frictionless wheels are attached to the bottom of a box, which is then measured and found to have a mass of 5.0 kg. The box is placed on the floor, and a student uses a brief horizontal force of 100 N to push the box sideways, after which the box rolls across the floor with constant velocity. How much Work does the floor do on the box as it rolls along?

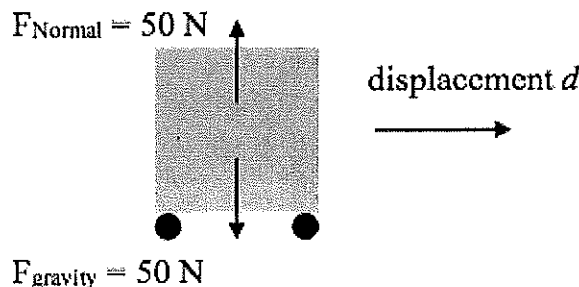
- 0 Joules
- About 50 Joules
- The answer can't be found without knowing how far the box traveled.
- The answer can't be found without knowing how far the student pushed the box.
- The answer can't be found without knowing the box's velocity.

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## Answer:

The correct answer is *a*.

Remember that the Work done on an object is found by multiplying the Force applied and the displacement of the object *in the same direction as the Force that was applied*.



Here, the forces acting on the box as it moves can be seen by drawing a free-body diagram of the box. Note that the Force applied by the floor—the Normal force—is upwards, while the displacement of the box is sideways. Because they are not in the same direction, there is no Work done by the floor on the box.

Another way of thinking about it is this: what is the displacement of the box *in the direction of the Force applied by the floor*? The floor is pushing up, but the box is clearly not moving up. Therefore, the floor is doing no Work on the box.

**Question:**

A student applies a constant force of 30 Newtons while lifting a heavy physics book up into the air a distance of 1.5 meters. How much Work does the student do on the book?

- a. 0 Joules, because gravity pulled down on the book
- b. 4.5 Joules
- c. 45 Joules
- d. The answer can't be found without knowing the mass of the book
- e. The answer can't be found without knowing the net Force on the book

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**Answer:**

The correct answer is **c**. The Work done by a Force is calculated by multiplying the force applied in a direction, and the distance the object travels in that same direction.

Here, we would calculate:

$$W = Fd$$

$$W_{\text{done by student}} = F_{\text{applied by student}} d$$

$$W_{\text{student}} = (30N)(1.5m) = 45J$$



**Question:**

How much does a spring with  $k = 500 \text{ N/m}$  need to be compressed in order to store  $7.0 \text{ J}$  of elastic potential energy?

**Solution:**

$$E_e = \frac{1}{2} k x^2$$

$$x = \sqrt{\frac{2E_e}{k}}$$

$$= \sqrt{\frac{2(7.0 \text{ Nm})}{500 \text{ N/m}}}$$

$$\boxed{x = 0.167 \text{ m}}$$

**Question:**

A student carries a large rock up a hill, and in the process does 500 J of Work on the rock. The student then releases the rock from the top of the hill and watches it roll down the mountain. How much Work does gravity do on the rock as it's rolling down the hill?

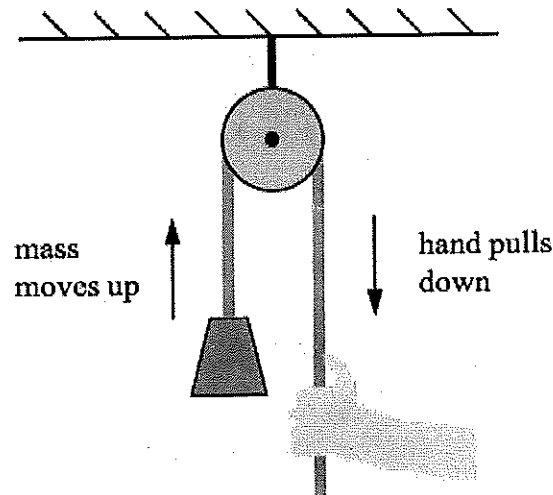
- a. -500 J
- b. 500 J
- c. 500 J – the energy lost to friction
- d. 500 J – the rotational kinetic energy of the rock
- e. none of these

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**Answer:**

The correct answer is *b*. The Work done by the gravity as the rock moves down the hill is exactly equal to the Work done in carrying it up the mountain, according to  $W = F \cdot x$ . It's true that the translational Kinetic energy of the rock after it has rolled down the hill will be somewhat less than it would be otherwise, due to both frictional "loss" of energy and the rotation of the rock, but this doesn't change the amount of work done by gravity.

**Question:**



A light, frictionless pulley is suspended from the ceiling and a rope is wrapped over the pulley. A large mass is attached to one end, and a student applies a force to the opposite end of the rope, pulling down in order to lift the mass up. Which of the following statements is *false*?

- The force of the mass pulling down on the left rope is equal to the force of tension in that rope pulling up on the mass.
- The force of the hand pulling down on the right rope is equal to the force of tension in that rope pulling up on the mass.
- The pulley in this case changes the direction of the force applied by the hand, but not the magnitude of the force.
- The Work done by the hand is equal to the change in gravitational potential energy for the mass as it rises.
- The tension in the right side rope is greater than the tension in the left side rope.

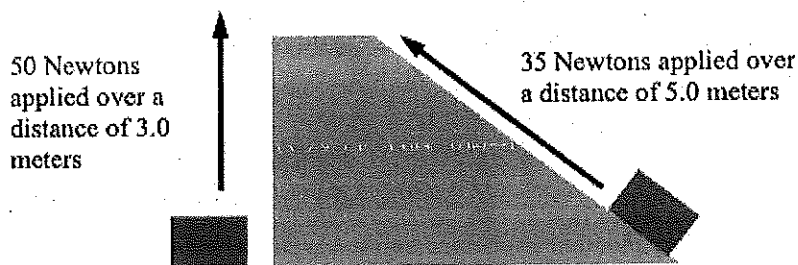
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**Answer:**

The correct answer is *e*. That statement is false; the tension in the ropes on either side of the pulley are equal.

All of the other statements are true. The tension in ropes is what allows them to transmit forces from one place to another, and Newton's Third Law of Motion describes the "equal and opposite" nature of these forces. On the left side, the force of the rope up on the mass and the force of the mass down on the rope are "equal in magnitude, opposite in direction." The same thing is true of the right side: the hand pulls down on the rope, and the rope pulls up on the hand. The tension that occurs in the right-hand rope (due to the hand pulling down on it) is transmitted to the left-hand rope where it is applied to the mass. The strength of that tension force hasn't changed—it's only pulling up now where on the right side of the pulley it was pulling down.

**Question:**



A 5.0-kilogram box is to be raised to the top of a 3.0-meter high platform. One student chooses to lift the block using a rope, applying a 50 Newton force over the 3.0 meter distance. The other student decides to push the box up a nearby ramp. There's some friction on the ramp, but a force of only 35 Newtons is required to move the box a distance of 5.0 meters. Which of the following statements is true?

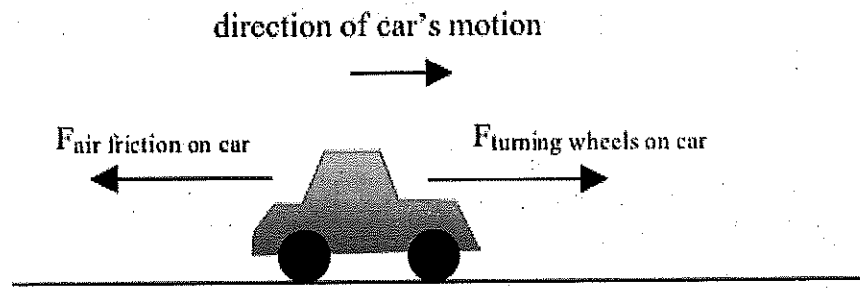
- Each student did the same amount of Work getting the box to the top of the ramp.
- The student on the left did more Work because a greater Force was applied during the lifting.
- The student on the left did less Work because the box was moved a shorter distance.
- The student on the right did less Work because the ramp provides a mechanical advantage.
- The student on the right did more Work because some energy was converted to heat via friction.

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**Answer:**

The correct answer is *e*. The student on the left does less Work—a total of 150 Joules, based on  $Work = Force \times distance$ —and the student on the right does 175 Joules of Work. The ramp does provide a Mechanical Advantage to the student on the right—the Force that student has to apply to push the box up the ramp is reduced—but that student does end up doing a little more Work in the end, because some of it is “lost” to frictional heat.

**Question:**



A car is traveling in the positive- $x$  direction as shown, driven forward by the Force of the road on the wheels, with air friction acting on the car to oppose its motion. If the car is traveling at a constant velocity, which statement is *false*?

- The force of the wheels on the car is greater than the force of air friction—that's why the car is moving.
- The force of the road on the wheels is doing positive Work on the car.
- The force of gravity is doing no Work on the car.
- The kinetic energy of the car is constant.
- There is no net Work being done on the car.

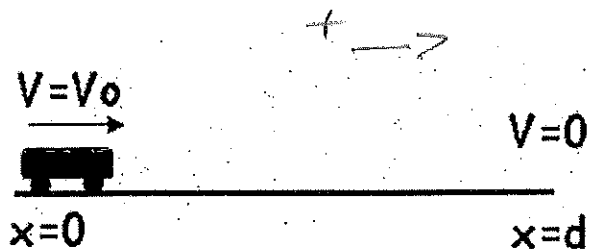
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**Answer:**

The correct answer is *a*. If the car is traveling at constant velocity, the forces acting on it must be balanced. Therefore, the Force between the tires and the road that propels the car forward and the opposing Force of air friction are, at this moment equal to each other.

The other statements are all true. The force of the road on the wheels is in the positive- $x$  direction, and causing a displacement of the car in that same direction. Gravity is doing no Work on the car because gravity is pulling *down* while the car is displacing sideways. The kinetic energy of the car is constant because it is moving at constant velocity. Finally the road (via the wheels) is doing positive Work on the car, but the force of air friction is doing negative Work on the car—thus the net Work being done on the car is zero.

Question:



At the position of  $X = 0$  a 2 kg cart with an initial velocity of 5 m/s is acted upon by a frictional force between the wheels and horizontal surface causing the cart to stop after moving a distance  $d$ , as shown in the figure above. Apply the work-energy principle to find the stopping distance  $d$ .

The coefficient of friction is 0.20

Solution:

$$W = \Delta E_K$$

$$\Delta E_K \rightarrow -$$

$$F_f d = E_{Kf} - E_{Ki}$$

$$-F_f d = -\frac{1}{2} m v^2$$

$$-\mu F_N d = -\frac{1}{2} m v^2$$

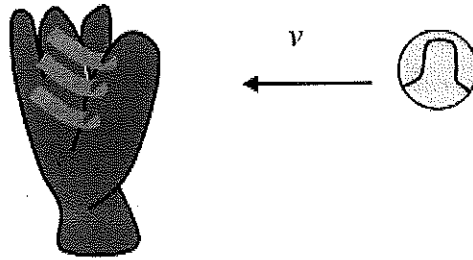
$$F_N = mg$$

$$-\mu mg d = -\frac{1}{2} m v^2$$

$$d = \frac{\frac{1}{2} v^2}{\mu g}$$

$$d = 6.38 \text{ m}$$

**Question:**



A baseball is traveling horizontally to the left when it is caught by a baseball glove. The force of the baseball on the glove causes the glove to move slightly to the left while it is catching the ball. Which statement is true?

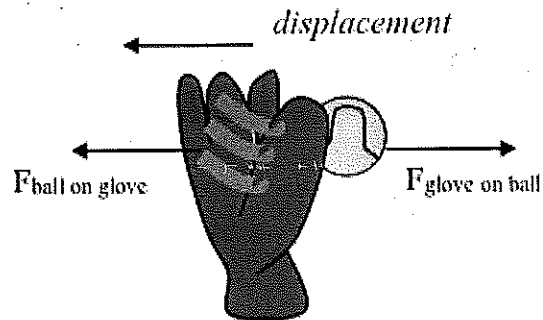
- a. The ball did positive Work on the glove, and the glove did negative Work on the ball.
- b. The ball did positive Work on the glove, and the glove did positive Work on the ball.
- c. The ball did negative Work on the glove, and the glove did positive Work on the ball.
- d. The ball did negative Work on the glove, and the glove did negative Work on the ball.
- e. The ball did positive Work on the glove, and the glove did no Work on the ball.

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**Answer:**

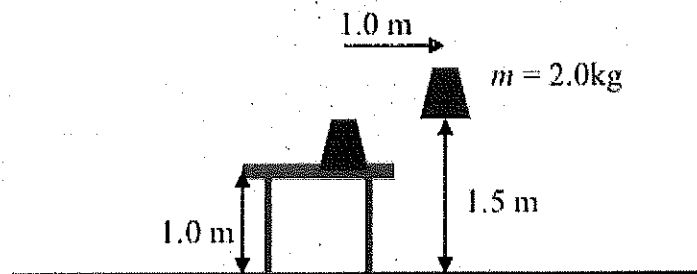
The correct answer is **a**.

Work done by the ball on the glove is positive because the Force and the displacement are in the same direction. You can tell Work is done on the glove because in the process of catching the ball, the glove is moved—some of the ball's energy is transferred to the glove. And that's what Work is, really: a *transfer* of energy, in this case from the ball to the glove.



Work done by the glove on the ball is negative because the Force of the glove on the ball and the displacement of the ball are in opposite directions. Another way of thinking about this is that glove *removed* energy from the ball in the process of catching it. The ball's energy was "subtracted" by the glove.

**Question:**



A teacher takes a 2.0 kilogram mass and lifts it 0.50 m above a table, that is itself 1.0 m above the floor. The teacher then moves the mass 1.0 meter to the side so that it is directly over the floor, 1.50 m below. Which statement is true?

- a. The teacher did 10.0 J of Work in lifting the mass.
- b. The mass has 30.0 J of GPE relative to the floor.
- c. The mass has 10.0 J of GPE relative to the table.
- d. The teacher did no Work against gravity when moving the mass 1.0 m to the side.
- e. All of the above are true.

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**Answer:**

The correct answer is **e**. This problem points out the fact that Gravitational Potential Energy is measured relative to some height. We typically indicate GPE relative to the ground, or the lowest surface nearby, but we can actually indicate GPE relative to *any* height.

$$W_{\text{done by teacher}} = GPE$$

$$W_{\text{done by teacher}} = mgh$$

$$W_{\text{done by teacher}} = (2.0\text{kg})(10\text{m/s}^2)(0.5\text{m})$$

$$W_{\text{done by teacher}} = 10\text{J}$$

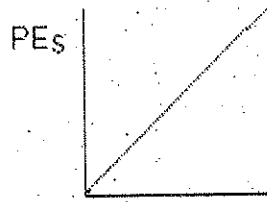
How can this be? 10.0 J and 30.0 J are not the same amount of GPE! Remember that GPE can also be thought of as a measure of how much Work was done to move the mass to that position. So it took the teacher 10.0 J of Work to lift the mass from the surface of the table, and it would have taken 30.0 J of Work to lift the mass from the floor, if that had been where it was located.

When we talk about Work, we're really talking about *changing* an object's GPE from one value to another. For this reason, it's often convenient to write  $\Delta GPE$ , which represents  $GPE_{\text{final}} - GPE_{\text{initial}}$ .

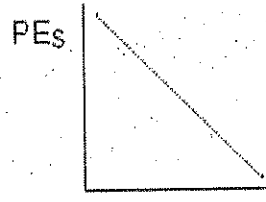


**Question:**

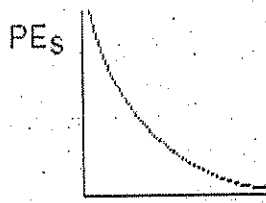
Which of the following graphs correspond to the elastic potential energy versus displacement for a spring?



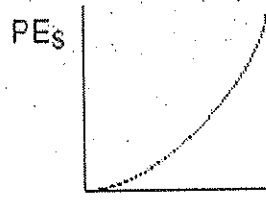
(1)



(3)



(2)



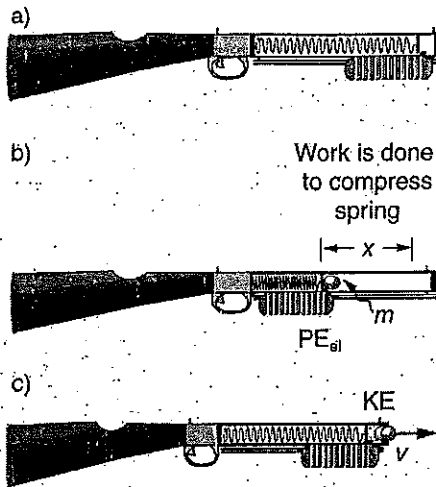
(4)

5 None of the above

**Answer:**

**Graph 4: Elastic potential energy varies quadratically with displacement.**

Question:



A force of  $2.5 \text{ N}$  is used to compress the spring of a toy gun that shoots small  $10 \text{ g}$  foam ball projectiles as shown in the figure above. If the spring has  $k = 50 \text{ N/m}$  and is compressed  $25 \text{ cm}$ , what will be the speed  $v$  of the projectiles as they emerge from the gun's barrel?

Solution:

$$W = \Delta E_K$$

$$F_a x = E_f - E_i \quad ?$$

$$F_a x = \frac{1}{2} m v_f^2$$

$$v_f = \sqrt{\frac{2 F_a x}{m}}$$

$$\sqrt{\frac{2(2.5 \text{ N})(.25 \text{ m})}{0.01 \text{ kg}}} \quad \left| v_f = 11.2 \frac{\text{m}}{\text{s}} \right|$$

**Question:**

Which of the following statements regarding Work and Energy is *false*?

- a. Work done by a force on an object *may* increase only its Kinetic Energy.
- b. Work done by a force on an object *may* increase only its Potential Energy.
- c. Work done by a force on an object *may* increase both its Kinetic and Potential Energies.
- d. Work done by a force on an object *may* cause no change in its energy.
- e. Work done by a force on an object requires that the object change its position.

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**Answer:**

The correct answer is *d*. Work done by a Force on an object results in a change in the energy of the object; this concept is called the *Work-Energy Theorem*. A force acting over a distance may lift an object in the air, increasing the gravitational potential energy, or it may act to speed up (or slow down) a moving object. Work done by a force on an object will always cause a change in its energy.

Note that the *net*, or *overall* Work done on an object may be zero. This would be the case if, for example, a student is pushing a desk across a floor, with a force equal to the force of friction acting between the desk and the floor. Here, Work done by the student increases the Kinetic Energy of the desk, but that energy is immediately converted to *heat* (internal Energy) by the force of friction. Both the student and the force of friction are doing Work on the desk, even if the overall energy of the desk remains constant.

**Question:**

A block of wood, initially moving along a rough surface, is pushed with an applied horizontal force  $F_{\text{applied}}$  that is less than the friction force  $F_{\text{friction}}$ . Which of the following statements is *false*?

- The Work being done by the applied force is negative.
- The net Work being done on the block is negative.
- The block is slowing down.
- The net Work being done on the box decreases its kinetic energy  $K$ .
- There is an increase in internal energy due to friction.

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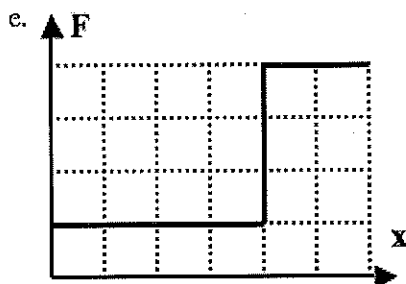
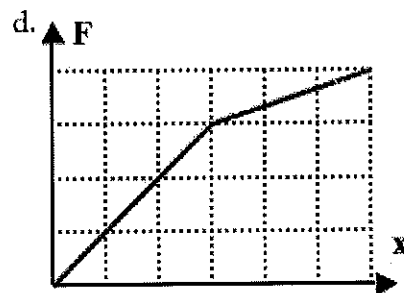
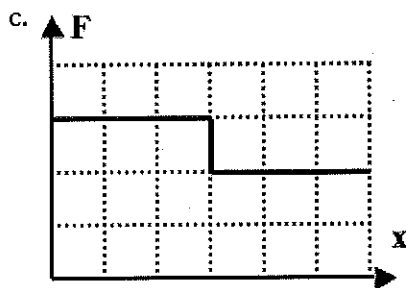
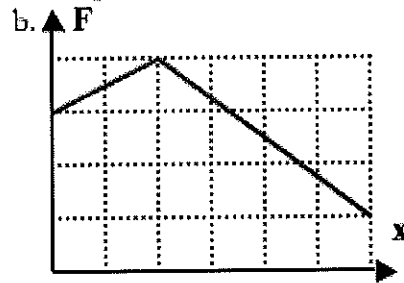
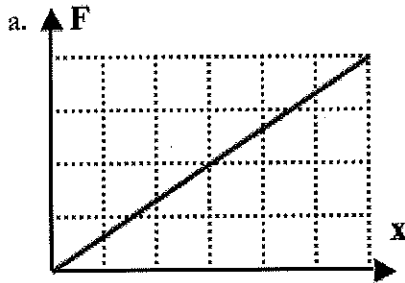
**Answer:**

The correct answer is *a*. Statement *a* is false because the work done by any single agent is  $W = Fx \cos\theta$ . Here, with the applied Force and the displacement of the box being in the same direction (or  $\cos\theta = \cos(0) = 1$ ), the Work being done by the applied force is positive, and goes toward increasing the box's kinetic energy.

Of course, the *net*, or overall, Work being done on the box has to include the force of Friction, which is acting in a direction opposite that of the box's displacement. Thus, Work done by friction is negative, which has the effect of converting some of the box's kinetic energy to internal energy via heat.

**Question:**

A box at rest on a horizontal frictionless surface is subjected to a net horizontal force in the  $x$ -direction. If the force varies with displacement  $x$  as described in the graphs below, after which situation will the block be traveling with the greatest speed?



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**Answer:**

The correct answer is *b*. This is a Work-Energy problem, in which Work being done on the box by the applied Force is going directly into increasing the kinetic energy  $K$  of the box: the greater the Work done by the Force, the greater the  $K$ —and thus the velocity—of the box.

Work is calculated as  $W = F \cdot x = Fx \cos \theta$  when the Force is a constant one. In this case, the force varies, so we need to use the calculus version of the formula:  $W = \int F_x \cdot dx$ . The integral means that we can use the area under the Force-displacement curve to determine the Work done.

In this case, the function that has the greatest area under the curve is *b*.

**Question:**

A student does Work by applying a horizontal force  $F$  to a table and moving it a horizontal distance  $d$  in a certain time  $t$ . In which situation would the student do *more* work?

- a. applying the same force over the same distance in a shorter time
- b. applying the same force over the same distance for a longer time
- c. applying half as much force for twice the distance
- d. applying the same force for a greater distance
- e. the question can't be answered without knowing if there is friction between the floor and the table

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**Answer:**

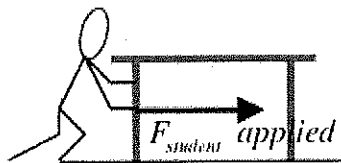
The correct answer is *d*. The amount of Work done by the student on the table is calculated according to  $Work = Force \cdot distance$ , where the Force and the distance are acting in the same direction. (A more complex version of this formula is  $W = Fx \cos \theta$ , where  $\theta$  is the angle between the direction of Force and the direction of the displacement.) Regardless of the time that it takes to accomplish the Work, if the same Force is applied over the same distance, the same amount of Work is done by that Force.

The amount of time that it takes to accomplish the Work is related to the *Power* used, where

$$Power = \frac{Work}{time}$$

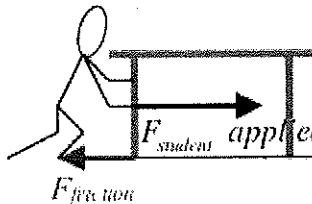
And while it's true that the presence of friction between the floor and the table will ultimately affect the table's speed, the Work done by the student remains

$Work_{student} = Force_{student} \cdot distance$ . This Work might translate direction into kinetic energy (if there is no "loss" of energy to friction), or a friction force may do "negative Work" on the table, reducing the amount of energy that is converted to kinetic. Either way, the Work done by the student remains the same.



$$W_{in} = KineticEnergy$$

In a frictionless situation, all of student's Work goes into kinetic energy.

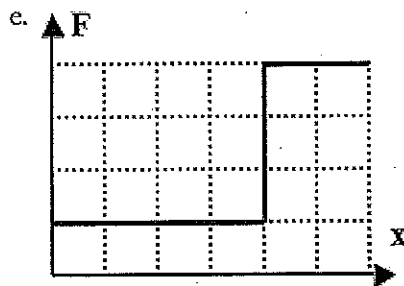
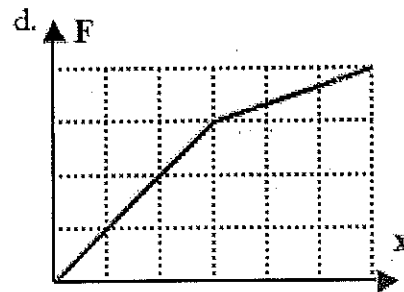
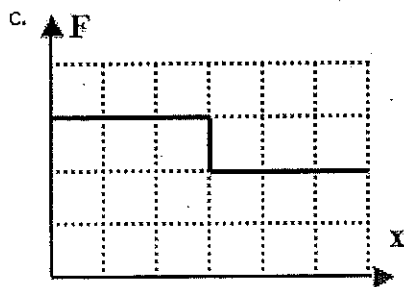
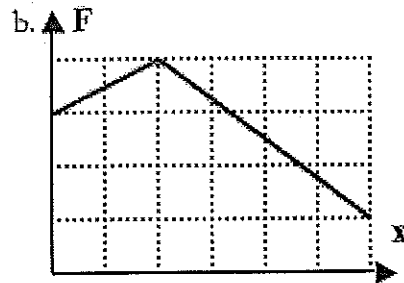
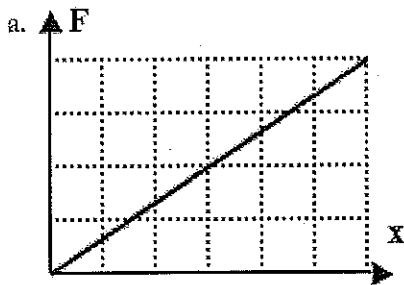


$$W_{in} = KineticEnergy + \Delta E_{int}$$

In a situation with friction, student does same Work on the table, but some of that energy is converted to internal "heat," so less energy goes into kinetic energy, and table has less velocity at the end.

Question:

As part of a high school physics experiment, five students take turns pushing an object across a horizontal floor over the same displacement. A sensor attached to the object measures the students' applied force in each case. The force vs displacement for each student is plotted and shown below. Which graph corresponds to the student that did the greatest amount of work in moving the object over the given distance?



- a. Graph a
- b. Graph b
- c. Graph c
- d. Graph d
- e. Graph e

Answer:

**Work = Area Under the Curve.**

Counting and comparing squares provides the answer.

Graph a ~ 12 Nm

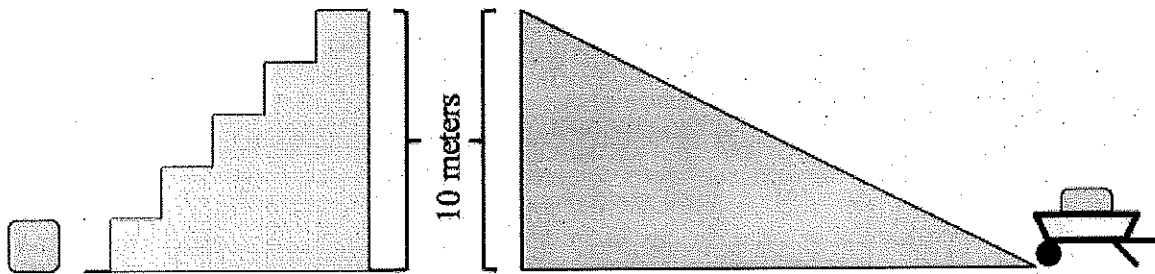
Graph b ~ 14.75 Nm

Graph c = 15 Nm

Graph d ~ 14.5 Nm

Graph e = 12 Nm

Question:



Two large masses—the gray boxes in the diagram above—need to be lifted to the top of a 10-meter high platform. One student takes his box up the green stairs while another student uses a wheelbarrow to roll her box up a ramp. Which of the following statements is true?

- The student on the left does more Work because he applies a greater Force lifting up against gravity.
- The student on the right does more Work because she has to travel a greater distance.
- The student on the left does less Work because she travels a shorter distance overall.
- Both students do the same Work because they apply the same Force in moving the masses.
- Both students do the same Work because their different Forces act over different distances.

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Answer:

The correct answer is *e*. The student going up the green stairs has to apply a greater force upwards against gravity while lifting the sack upwards 10 vertical meters. The student on the red ramp has to travel farther up the ramp, but is applying a smaller force in the process of pushing the wheelbarrow along the ramp. In the end, however, the amount of Work done by both students is the same.

$$\text{Work} = \text{Force} \times \text{distance} = \text{Force} \times \text{distance}$$

Green stairs                      Red ramp

You can verify this by asking yourself how much gravitational potential energy each box has at the end. Because they have the same potential energy, the Work done to get them up there must be the same.