Physics 8 — Wednesday, October 2, 2019

- This week, you finished reading Ch10 (motion in a plane).
- The next few chapters (10,11,12) are the most difficult material in the course. We will slow down for them. After that, the fun begins: we can apply our knowledge of forces (ch8), vectors (ch10), and torque (ch12) to structures.
- My main goal for today is for us to practice the ideas that you'll use on this week's homework #5. Toward that end:

Stretching a certain spring 0.10 m from its equilibrium length requires 10 J of work. How much more work does it take to stretch this spring an additional 0.10 m from its equilibrium length?

(A) No additional work

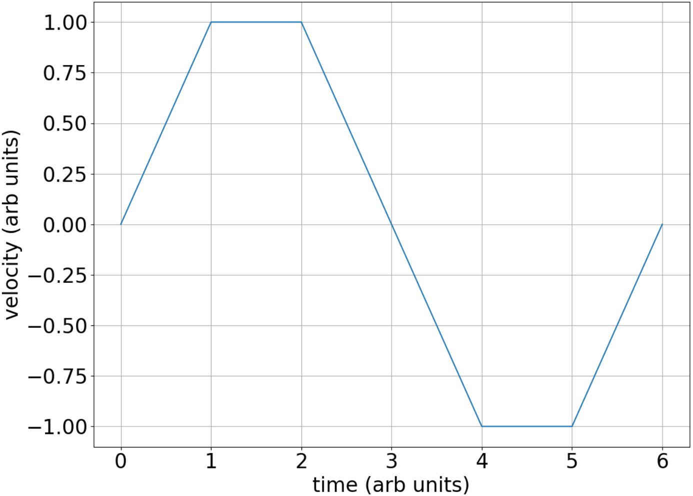
(B) An additional 10 J

(C) An additional 20 J

(D) An additional 30 J

(E) An additional 40 J

The velocity of an object as a function of time is shown. Over what time intervals is the work done on the object (a) positve, (b) negative, (c) zero? Hint: make a table showing sign of acceleration (hence sign of net force), sign of displacement, and sign of their product, for each segment. (Consider work done by whatever external force is causing the object's velocity to change.)



From a bridge at initial height h above the water, I release from rest an object of mass m which is attached to a "bungee cord" (a spring) of relaxed length ℓ_0 spring constant k. Which equation correctly expresses, assuming that no mechanical energy is dissipated into heat, the speed v_f of the object when it reaches the water surface? (One end of the bungee cord is tied to the bridge. The cord is initially slack does not begin to stretch until the object has fallen a distance equal to the cord's relaxed length.)

(A) $mg = kh$

(B) $mg = k\,(h - \ell_0)$

(C) $mgh + \frac{1}{2}mv_f^2 = \frac{1}{2}kh^2$

(D) $mgh + \frac{1}{2}mv_f^2 = \frac{1}{2}k\,(h - \ell_0)^2$

(E) $mgh = \frac{1}{2}mv_f^2 + \frac{1}{2}kh^2$

(F) $mgh = \frac{1}{2}mv_f^2 + \frac{1}{2}k\,(h - \ell_0)^2$

A motor lifts an object of mass m at constant upward **velocity** $v_y = \mathrm{d}y/\mathrm{d}t$. How much power (work per unit time) does the motor supply?

(A) $\text{power} = mgv_y$

(B) $\text{power} = mgy$

(C) $\text{power} = \frac{1}{2}mv_y^2$

(D) $\text{power} = \frac{1}{2}mv_y^2 + mgy$

(E) $\text{power} = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{1}{2}mv_y^2 + mgy\right)$

(F) (A) and (E) are both correct.

(G) (B) and (E) are both correct.

A motor lifts an object of mass m at constant upward **acceleration** $a_y = \mathrm{d}v_y/\mathrm{d}t$. How much power (work per unit time) does the motor supply?

(A) $\text{power} = mgv_y$

(B) $\text{power} = m(a_y + g)v_y$

(C) $\text{power} = \frac{1}{2}mv_y^2$

(D) $\text{power} = \frac{1}{2}mv_y^2 + mgy$

(E) $\text{power} = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{1}{2}mv_y^2 + mgy\right)$

(F) (A) and (E) are both correct.

(G) (B) and (E) are both correct.

An object is said to be in *stable equilibrium* if a displacement in either direction requires positive work to be done on the object by an external force. Let's suppose that there is some potential energy associated with every position of the object, i.e. there is a potential energy curve $U(x)$, where x is the object's position. How do you expect $U(x)$ to change as you move the object away (in either direction) from its position of stable equilibrium?

(A) When displacing the object away from its equilibrium position, the positive work done (on the object plus its environment) by the external force causes a positive change in the potential energy function $U(x)$. So $U(x)$ must have a local minimum at the object's stable equilibrium position.

(B) $U(x)$ must have a local maximum at the object's stable equilibrium position.

(C) The derivative $\mathrm{d}U(x)/\mathrm{d}x$ must have a local minimum at the object's stable equilibrium position.

(D) The derivative $\mathrm{d}U(x)/\mathrm{d}x$ must be zero at the object's stable equilibrium position.

(E) Both (A) and (D) are true.

From a height h above the ground, I throw a ball with an initial velocity that is nonzero only in the horizontal direction: $v_{xi} > 0$, $v_{yi} = 0$. How do I determine how long it takes to reach the ground?

(A) $h + v_{xi}t = 0$

(B) $h + v_{xi}t - \frac{1}{2}gt^2 = 0$

(C) $h + v_{yi}t = 0$

(D) $h - \frac{1}{2}gt^2 = 0$

From a height h above the ground, I throw a ball with an initial velocity that is nonzero only in the horizontal direction: $v_{xi} > 0$, $v_{yi} = 0$. If the ball's initial x coordinate is $x_i = 0$, how do I determine the x coordinate where the ball hits the ground?

(A) $x_f = h + v_{xi}t - \frac{1}{2}gt^2$, with t given on the previous page

(B) $x_f = h + v_{xi}t - \frac{1}{2}gt^2$, with $t = 0$

(C) $x_f = x_i + v_{xi}t$, with t given on the previous page

(D) $x_f = x_i + v_{xi}t$, with $t = 0$

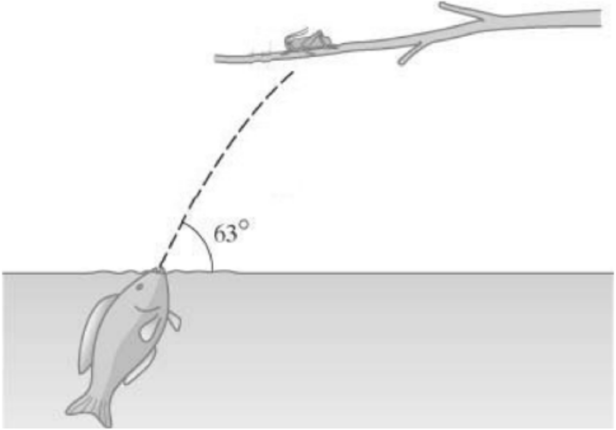
(E) $y_f = y_i + v_{xi}t$, with t given on the previous page

(F) $y_f = y_i + v_{xi}t$, with $t = 0$

From a height h above the ground, I throw a ball with an initial velocity that is nonzero only in the horizontal direction: $v_{xi} > 0$, $v_{yi} = 0$. How do I determine the x and y coordinates of the ball's velocity, v_x and v_y, at the instant before the ball hits the ground?

We stopped before we got here.

6. The archer fish shown in the figure, peering from just below the surface of the water, spits a drop of water at the grasshopper and knocks it into the water. The grasshopper's initial position is 0.45 m above the water surface and 0.25 m horizontally away from the fish's mouth. If the launch angle of the drop of water is 63° with respect to the horizontal water surface, how fast is the drop moving when it leaves the fish's mouth?



A block initially at rest is allowed to slide down a frictionless ramp and attains a speed v at the bottom. To achieve a speed $2v$ at the bottom, how many times as high must a new ramp be?

(A) 1

(B) 1.414

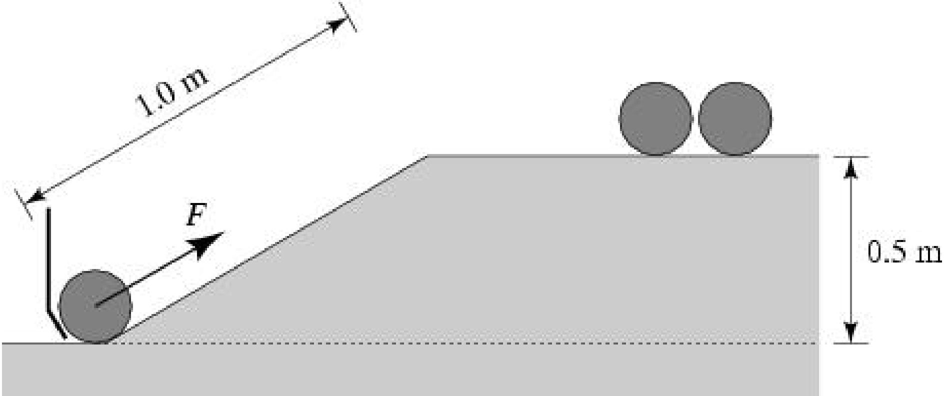
(C) 2

(D) 3

(E) 4

(F) 5

(G) 6



At the bowling alley, the ball-feeder mechanism must exert a force to push the bowling balls up a 1.0 m long ramp. The ramp leads the balls to a chute 0.5 m above the base of the ramp. About how much force must be exerted on a 5.0 kg bowling ball?

(A) 200 N

(B) 100 N

(C) 50 N

(D) 25 N

(E) 5.0 N

(F) impossible to determine.

Suppose you drop a 1 kg rock from a height of 5 m above the ground. When it hits, how much force does the rock exert on the ground? (Take $g \approx 10\ \mathrm{m/s^2}$.)

(A) 0.2 N

(B) 5 N

(C) 50 N

(D) 100 N

(E) impossible to determine without knowing over what distance the rock slows when it impacts the ground.

Chapter 9 reading question

2. When you stand up from a seated position, you push down with your legs. So then do you do negative work when you stand up?

"In this situation, we have 2 systems. Firstly, in the system of just the person, the action of standing up will result in a loss of internal or chemical energy, thereby resulting in a loss of system energy and hence positive work (BY the system) [which implies negative work done ON the system, by Earth's gravitational force]. For the system of the person and Earth, the action of standing up increases the person's potential energy at the expense of internal energy. In this situation, there is no change in system energy and therefore no work is done."

Reading question 2 had no really simple answer

When you stand up from a seated position, you push down with your legs. Does this mean you do negative work when you stand up?

Suppose "system" $=$ me $+$ Earth $+$ floor $+$ chair

- $\Delta K = 0$
- $\Delta U = mg\ (\Delta x)_{\text{my c.o.m.}} > 0$
- $\Delta E_{\text{thermal}} = 0$ (debatable but irrelevant)
- $\Delta E_{\text{source}} = -mg\ (\Delta x)_{\text{my c.o.m.}} < 0$

- $W = 0$

There are no external forces. Everything of interest is inside the system boundary.

Let's try choosing a different "system."

When you stand up from a seated position, you push down with your legs. Does this mean you do negative work when you stand up?

Suppose "system" = me + floor + chair

- $\Delta K = 0$
- $\Delta U = 0$ (U^G undefined if Earth not in system)
- $\Delta E_{\rm thermal} = 0$ (debatable but irrelevant)
- $\Delta E_{\rm source} = -mg\ (\Delta x)_{\rm my\ c.o.m.} < 0$
- $W = -mg\ (\Delta x)_{\rm my\ c.o.m.} < 0$

External gravitational force, exerted by Earth on me, does negative work on me. Point of application of this external force is my body's center of mass. Force points downward, but displacement is upward. $W < 0$. System's total energy decreases.

Let's try answering a slightly different question.

When ***a friend*** *stands me up from a chair (e.g. my knees are weak today), does my friend do positive or negative work?*

Suppose "system" = me + Earth + floor + chair

- $\Delta K = 0$
- $\Delta U = mg\ (\Delta x)_{\text{my c.o.m.}} > 0$
- $\Delta E_{\text{thermal}} = 0$ (debatable but irrelevant)
- $\Delta E_{\text{source}} = 0$

- $W = mg\ (\Delta x)_{\text{my c.o.m.}} > 0$

My friend applies an upward force beneath my arms. The point of application of force is displaced upward.

Let's include my friend as part of "the system."

When a friend stands me up from a chair (e.g. my knees are weak today), does my friend do positive or negative work?

Suppose "system" = me + Earth + floor + chair + friend

- $\Delta K = 0$
- $\Delta U = mg\ (\Delta x)_{\text{my c.o.m.}} > 0$
- $\Delta E_{\text{thermal}} = 0$ (debatable but irrelevant)
- $\Delta E_{\text{source}} = -mg\ (\Delta x)_{\text{my c.o.m.}} < 0$
- $W = 0$

There is no external force. Everything is within the system.

Back to the original reading question

When you stand up from a seated position, you push down with your legs. Does this mean you do negative work when you stand up?

I think the work done **ON the system BY my legs** is either positive (if my legs are considered "external" to the me+Earth+floor system and are supplying the energy to lift me) or zero (if my legs are part of the system).

Remember the one way we got a negative answer: In the case in which Earth was not part of the system, we found that the external force of Earth's gravity did negative work on me. But I was pushing Earth downward, away from me. I lost energy. So even in this case (where the work done **on me** was negative), the work done **by me** was positive.

Key point: what you call "work" depends on how you define "the system."

A few key ideas from Chapters 8 (force) and 9 (work)

Impulse (i.e. momentum change) delivered by external force:

$$\text{force} = \frac{\mathrm{d}(\text{momentum})}{\mathrm{d}t} \quad \Leftrightarrow \quad \vec{J} = \int \vec{F}_{\text{external}}\, \mathrm{d}t$$

External force exerted ON system:

$$\text{force} = \frac{\mathrm{d}(\text{work})}{\mathrm{d}x} \quad \Leftrightarrow \quad W = \int F_x\, \mathrm{d}x$$

Force exerted BY spring, gravity, etc.:

$$\text{force} = -\frac{\mathrm{d}(\mathit{potential\ energy})}{\mathrm{d}x}$$

ΔE_{system} = flow of energy into system = work done ON system:

$$\text{work} = \Delta(\text{energy}) = \Delta K + \Delta U + \Delta E_{\text{source}} + \Delta E_{\text{thermal}}$$

Notice that work : energy :: impulse : momentum

Some equation sheet entries for Chapters 8+9

http://positron.hep.upenn.edu/physics8/files/equations.pdf

Work (external, nondissipative, 1D):

$$W = \int F_x(x)\ dx$$

which for a constant force is

$$W = F_x\ \Delta x$$

Power is rate of change of energy:

$$P = \frac{\mathrm{d}E}{\mathrm{d}t}$$

Constant external force, 1D:

$$P = F_x v_x$$

G.P.E. near earth's surface:

$$U_{\mathrm{gravity}} = mgh$$

Force of gravity near earth's surface (force is $-\frac{\mathrm{d}U_{\mathrm{gravity}}}{\mathrm{d}x}$):

$$F_x = -mg$$

Potential energy of a spring:

$$U_{\mathrm{spring}} = \frac{1}{2}k(x - x_0)^2$$

Hooke's Law (force is $-\frac{\mathrm{d}U_{\mathrm{spring}}}{\mathrm{d}x}$):

$$F_{\mathrm{by\ spring\ ON\ load}} = -k(x - x_0)$$

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- Remember HW5 due this Friday.
- HW help: Greg Wed 4–6 DRL 3C4, Bill Thu 6–8 DRL 2C4.