Physics 8 — Friday, September 27, 2019

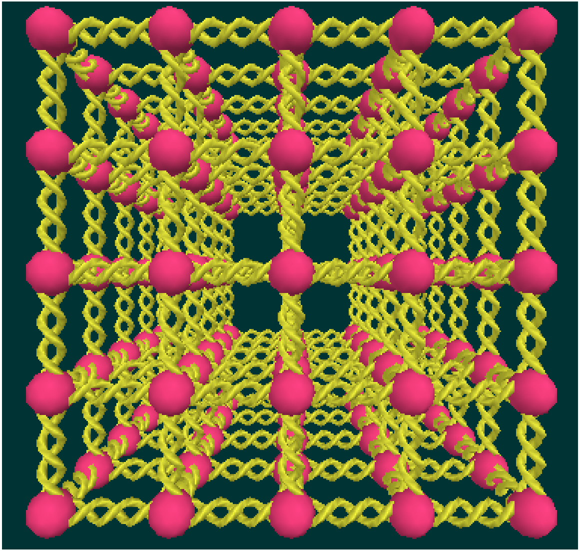
- Turn in HW#4. Pick up handout for HW#5, which covers Ch9 and starts Ch10.
- For Monday, finish reading Ch10 (motion in a plane).
- If you have little or no coding experience and you're interested in an XC option to learn Python for quantitative tasks like graphing and modeling data, email me ASAP.
- Wolfram Mathematica is free (site license) for SAS and Wharton students. I have some very helpful self-study Mathematica materials you can do for XC. Email if interested.
- If you're interested in learning to do a bit of Python coding in a drawing/animation system called "Processing" made by and for visual artists, you can look at my Fall 2017 day-before-Thanksgiving lecture here: `http://xray.hep.upenn.edu/wja/p008/2017/files/phys8_notes_20171122.pdf`
- Before class: draw FBDs (copy slide 8 to board)

(Begin digression.)

Dissipative / incoherent / irreversible

A simple ball / spring model of the atoms in a solid.

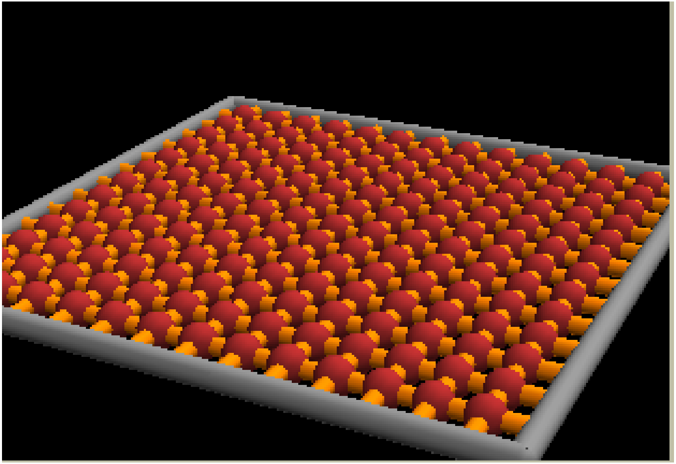
This is sometimes a useful picture to keep in your head.



Dissipative / incoherent / irreversible

2D version for simplicity

illustrate "reversible" and "irreversible" deformation with e.g. marbles and egg crate



Dissipative / incoherent / irreversible

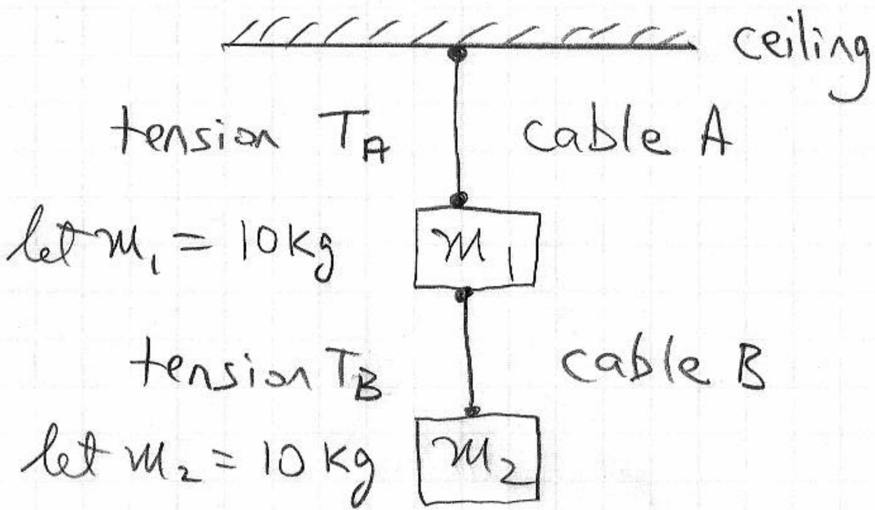
I showed you once before my low-tech animation of two objects in a totally inelastic collision. Collision dissipates coherent motion (kinetic energy) into incoherent vibration of atoms (thermal energy)

https://youtu.be/SJIKCmg2Uzg

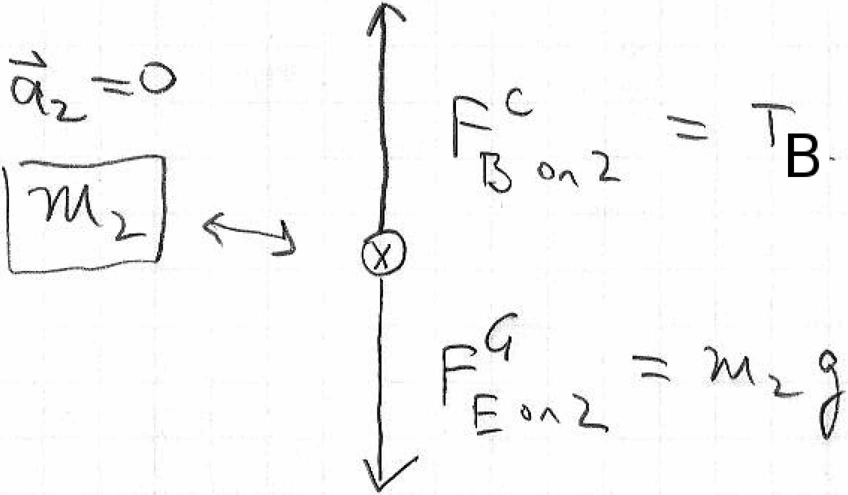
Here's a high-speed movie of a (mostly) reversible process a golf ball bouncing off of a wall at 150 mph.

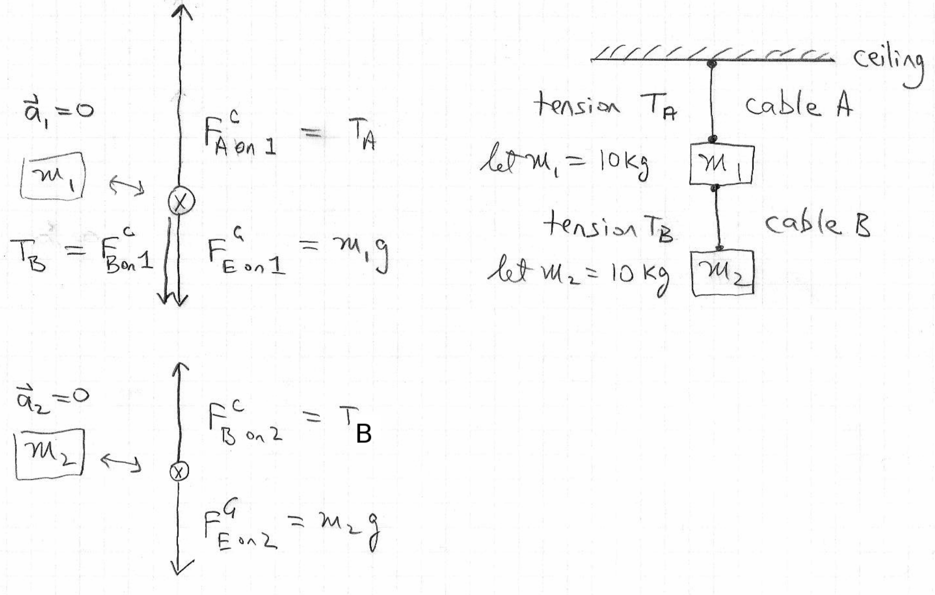
https://www.youtube.com/watch?v=AkB81u5IM3I

(End digression.)

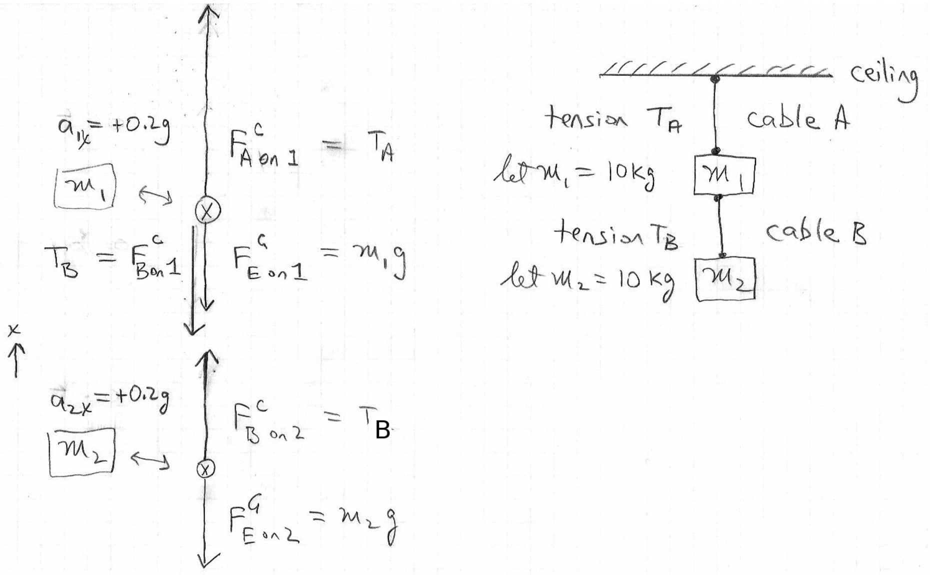


Work with your neighbor to draw a FBD for mass 2. Then draw a FBD for mass 1. Assume that $\vec{a} = \vec{0}$ for both masses.

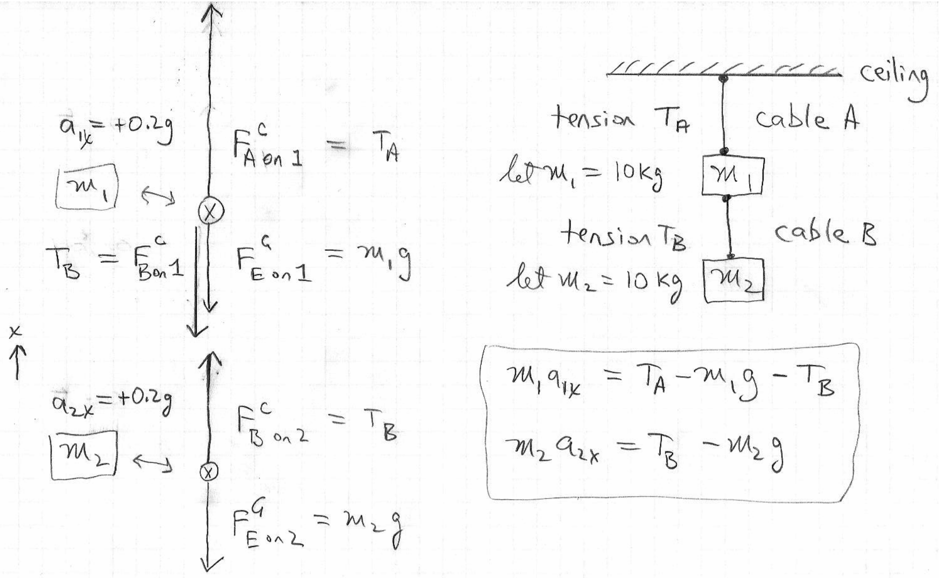

$\vec{a}_2 = 0$
m_2
$F^{C}_{B\,on\,2} = T_B$
$F^{G}_{E\,on\,2} = m_2 g$



Next: How would these two diagrams change if we imagine that the ceiling is actually the ceiling of an elevator that is **accelerating upward** at $a_x = +1.96\,\mathrm{m/s^2}$ (that's $0.2g$ — you can round off).



How do you use these two FBDs to write Newton's 2nd law for each of the two masses?



Note: because the length of an (**idealized**) taut cable doesn't change as its tension increases, $a_{1x} = a_{2x}$. Distance between blocks only changes if the cable goes slack (no longer in tension).

(Skip to slide 23.)

HW4 / problem 9: slightly modified (skip?)

9*. A tugboat pulls two barges (connected in series, like a train, with taut ropes as couplings) down a river. The barge connected to the tugboat, carrying coal, has inertia m_1. The other barge, carrying pig iron, has inertia m_2. The frictional force exerted by the water on the coal barge is F^f_{w1}, and that exerted by the water on the pig-iron barge is F^f_{w2}. The common acceleration of all three boats is a_x. Even though the ropes are huge, the gravitational force exerted on them is negligible, as are the ropes' inertias. How can you solve for the tension in each rope?

HW4 / problem 10 (modified): (skip?)

10*. A red cart of mass m_{red} is connected to a green cart of mass m_{green} by a **relaxed** spring of spring constant k. The green cart is resting against a blue cart of mass m_{blue}. All are on a low-friction track. You push the red cart to the right, in the direction of the green cart, with a constant force $F^{c}_{\text{you,green}}$. (a) What is the acceleration of the center-of-mass of the three-cart system? (b) What is the acceleration of each cart **the instant you begin to push**? (c) What is the acceleration of each cart the instant when the spring is compressed a distance D with respect to its relaxed length?

(skip?)

Estimate the spring constant of your car springs. (Experiment: sit on one fender.)

(What do you think?)

(skip)

When a 5.0 kg box is suspended from a spring, the spring stretches to 1.0 m beyond its equilibrium length. In an elevator accelerating upward at 0.98 $\mathrm{m/s^2}$ (that's "0.1 g"), how far will the spring stretch with the same box attached?

(A) 0.50 m

(B) 0.90 m

(C) 1.0 m

(D) 1.1 m

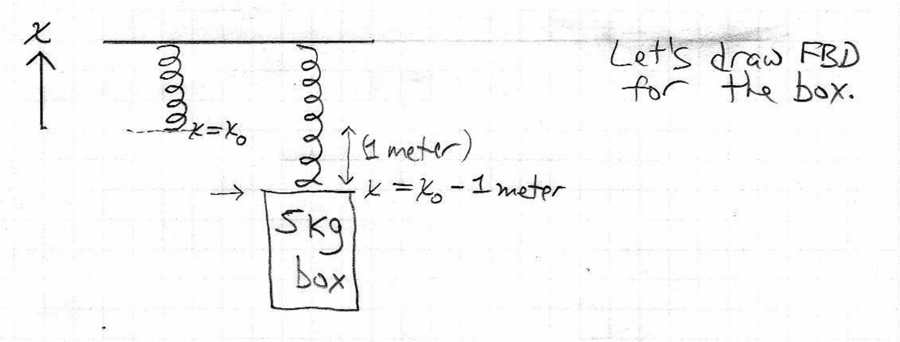
(E) 1.2 m

(F) 1.9 m

(G) 2.0 m

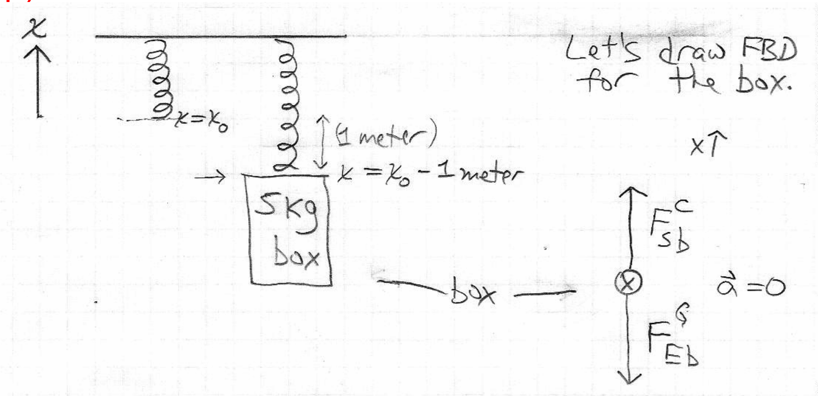
(By the way: When a tall building sways back and forth in the wind, the uncomfortable acceleration experienced by the occupants is often measured as a fraction of "g.")

(skip)



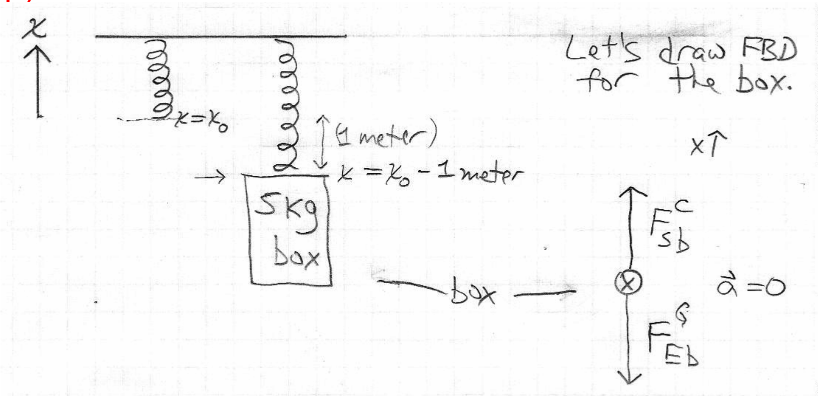
Let's start by drawing a FBD for the box when the elevator is **not** accelerating.

(skip)



x
x = x0
(1 meter)
x = x0 - 1 meter
5kg box
box
Let's draw FBD for the box.
x
F sb c
F Eb g
a = 0

(skip)



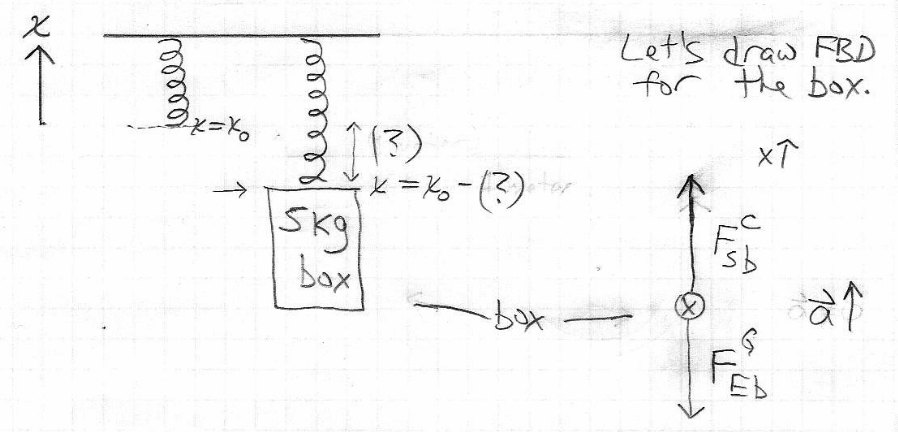
$$F^c_{sb,x} + F^G_{Eb,x} = ma_x = 0$$

$$F^c_{sb,x} = -k\,(x - x_0) = -k(-1\ \mathrm{meter}) \qquad F^G_{Eb,x} = -mg$$

$$+k(1\ \mathrm{meter}) - mg = ma_x = 0$$

Next, what happens if elevator is accelerating upward at $1\ \mathrm{m/s^2}$?

(skip)



$$F^c_{sb,x} + F^G_{Eb,x} = ma_x = +1\ \mathrm{m/s^2}$$

$$F^c_{sb,x} = -k\,(x - x_0) \qquad F^G_{Eb,x} = -mg$$

$$-k(x - x_0) - mg = ma_x = +0.1mg$$

combine with $+k(1\ \mathrm{meter}) - mg = 0$ from last page

(skip)

$$-k(x - x_0) - mg = ma_x = +0.1g \quad \Rightarrow \quad \boxed{-k(x - x_0) = +1.1mg}$$

combine with $+k(1 \text{ meter}) - mg = 0 \quad \Rightarrow \quad \boxed{+k(1 \text{ meter}) = mg}$

Divide two boxed equations: get $\quad x - x0 = -1.1 \text{ meters}$

So the spring is now stretching 1.1 meters beyond its relaxed length (vs. 1.0 meters when $a_x = 0$).

The upward force exerted by the spring on the box is $\quad m(g + a_x)$.

(skip)

When a 5.0 kg box is suspended from a spring, the spring stretches to 1.0 m beyond its equilibrium length. In an elevator accelerating upward at 0.98 $\mathrm{m/s^2}$, how far will the spring stretch with the same box attached?

(A) 0.50 m

(B) 0.90 m

(C) 1.0 m

(D) 1.1 m

(E) 1.2 m

(F) 1.9 m

(G) 2.0 m

In the 17th century, Otto von Güricke, a physicist in Magdeburg, fitted two hollow bronze hemispheres together and removed the air from the resulting sphere with a pump. Two eight-horse teams could not pull the halves apart even though the hemispheres fell apart when air was readmitted. Suppose von Güricke had tied both teams of horses to one side and bolted the other side to a giant tree trunk. In this case, the tension on the hemispheres would be

(A) twice

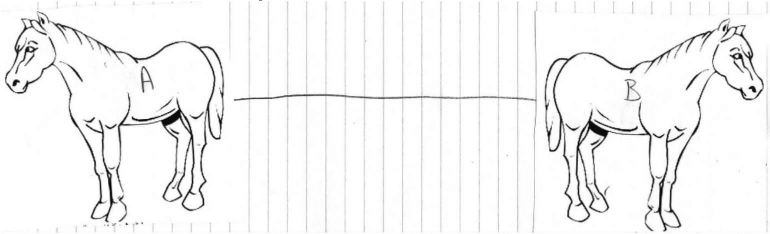
(B) exactly the same as

(C) half

what it was before.

(To avoid confusion, you can replace the phrase “the hemispheres” with the phrase “the cable” if you like. The original experiment was a demonstraton of air pressure, but we are interested in tension.)

Suppose a horse can pull 1000 N



$$\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$$

$$|\vec{F}_{A \text{ on } B}| = |\vec{F}_{B \text{ on } A}| = 1000 \text{ N}$$

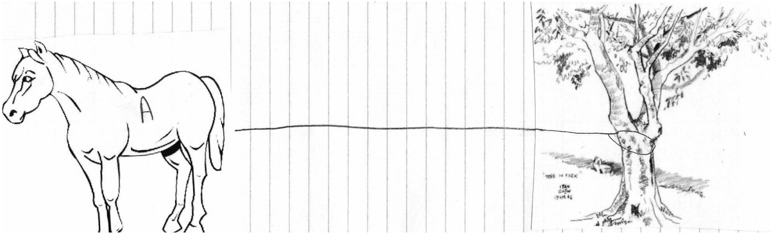
$$T = 1000 \text{ N}$$

$$\vec{a}_A = \vec{0}$$

$$\vec{a}_B = \vec{0}$$

The acceleration of each horse is zero. What are the two horizontal forces acting on horse A? What are the two horizontal forces acting on horse B?

Suppose tree stays put, no matter how hard horse pulls



$$\vec{F}_{A \text{ on tree}} = -\vec{F}_{\text{tree on } A}$$

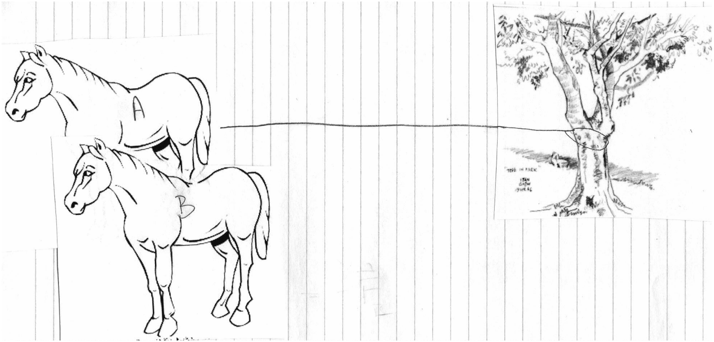
$$|\vec{F}_{A \text{ on tree}}| = |\vec{F}_{\text{tree on } A}| = 1000 \text{ N}$$

$$T = 1000 \text{ N}$$

$$\vec{a_A} = \vec{0}$$

What are the two horizontal forces acting on horse A?

Suppose tree stays put, no matter how hard horses pull. Somehow we attach both horses to the left end of the same cable.



$$\vec{F}_{A+B \text{ on tree}} = -\vec{F}_{\text{tree on } A+B}$$

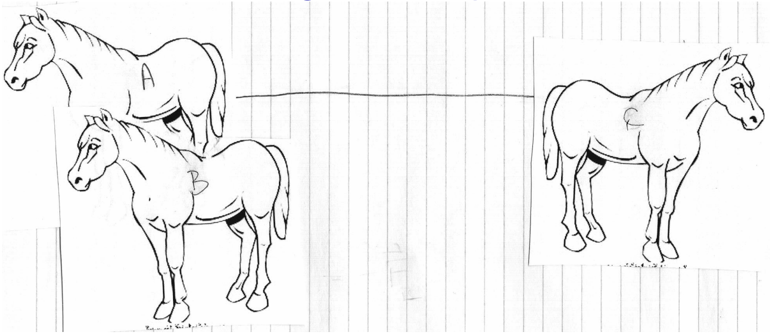
$$|\vec{F}_{A+B \text{ on tree}}| = |\vec{F}_{\text{tree on } A+B}| = 2000 \text{ N}$$

$$T = 2000 \text{ N}$$

$$\vec{a}_{\text{horses}A+B} = \vec{0}$$

What are the external forces acting on the two-horse system (system = horse A + horse B)?

Horse C loses his footing when he pulls > 1000 N



$$|\vec{F}_{A+B \text{ on C}}| = |\vec{F}_{\text{C on } A+B}| = 2000 \text{ N}$$

$$T = 2000 \text{ N}$$

Force of ground on C is 1000 N to the right. Tension pulls on C 2000 N to the left. C accelerates to the left.

$$|\vec{a_C}| = (2000 \text{ N} - 1000 \text{ N})/m_C$$

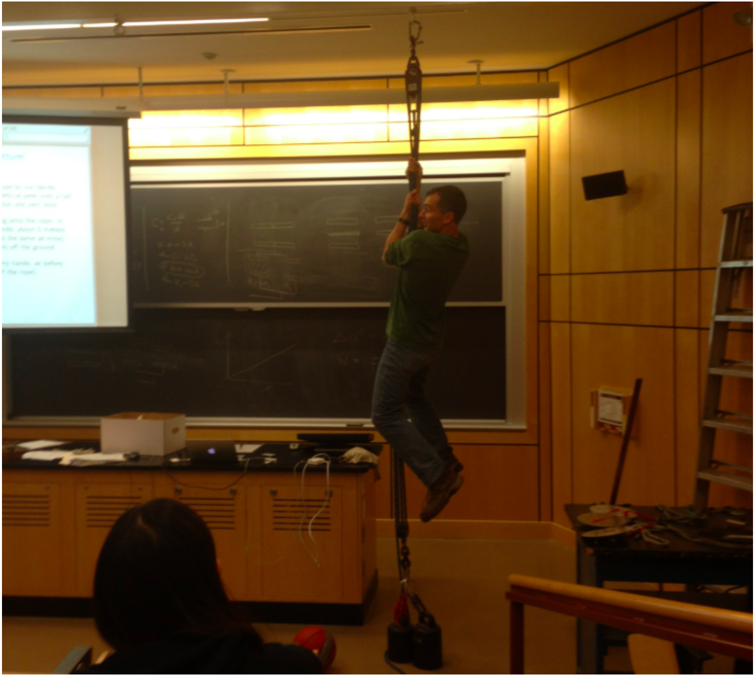
Today, while we happen to have this rope attached to the ceiling, I want to re-visit something (related to forces) that I demonstrated on the first day of class. Believe it or not, this relates pretty directly to architecture.

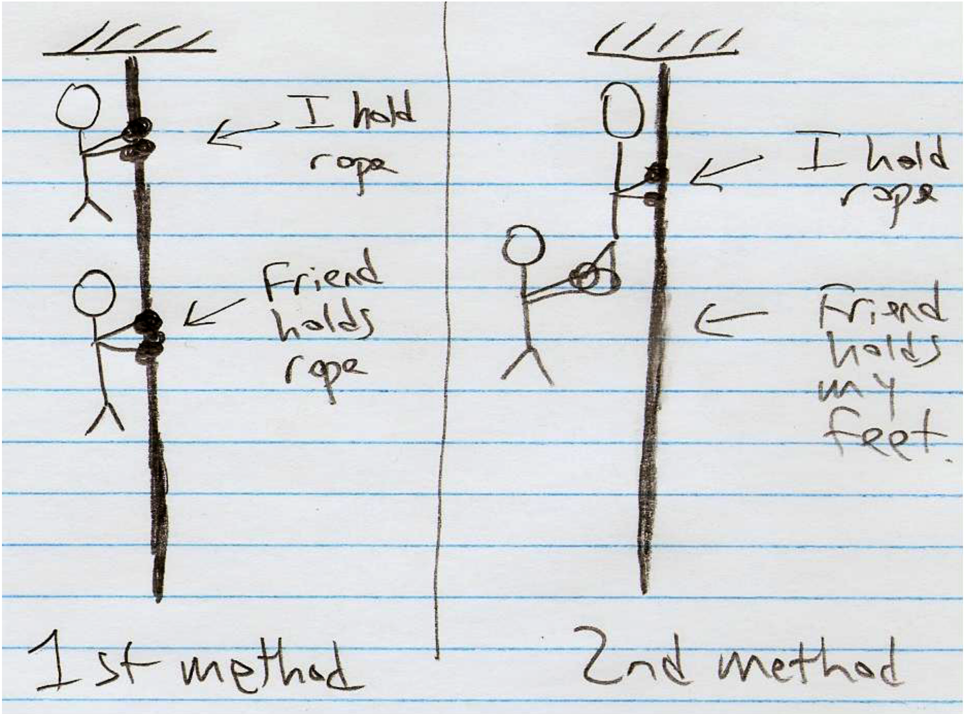
My friend and I both want to hang on to a rope by our hands, perhaps because being up above the ground lets us peek over a tall fence and see into an amazing new construction site next door.

We consider two different methods of hanging onto the rope. In the first method, I hold the rope with my hands, about 5 meters off the ground, and my friend (whose mass is the same as mine) holds the rope with his hands, about 3 meters off the ground.

In the second method, I told the rope with my hands, as before, and my friend holds onto my feet (instead of the rope).

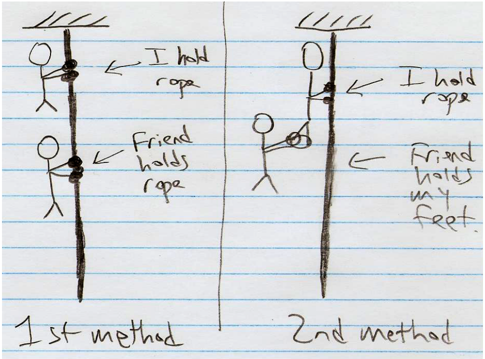
Let's draw a picture, to make it more clear.





I hold rope
Friend holds rope
1st method
I hold rope
Friend holds my feet.
2nd method

The downward force exerted by *my* hands on the rope is . . .



(A) The same for both methods: equal to mg (m = my mass)

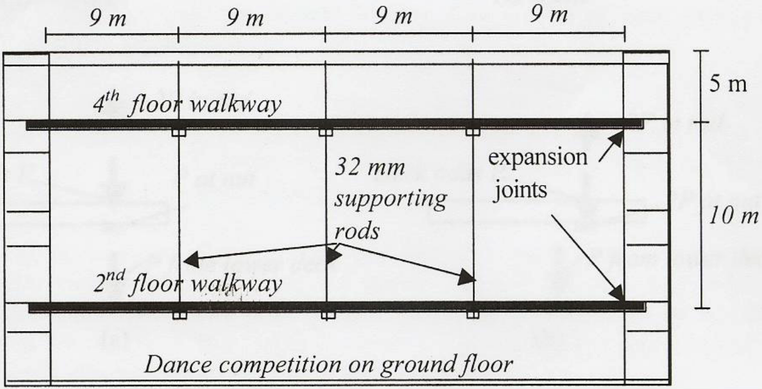
(B) The same for both methods: equal to $2mg$

(C) Twice as much for 1st method ($2mg$ vs. mg)

(D) Twice as much for 2nd method ($2mg$ vs. mg)

Kansas City Hyatt Regency skywalk collapse

On 7^{th} July *1981*, a dance was being held in the lobby of the Hyatt Regency Hotel, Kansas City. As spectators gathered on suspended walkways above the dance floor, the support gave way and the upper walkway fell on the lower walkway, and the two fell onto the crowded dance floor, killing *114* people and injuring over *200*.



For more like this, read *To Engineer is Human* by Henry Petroski.

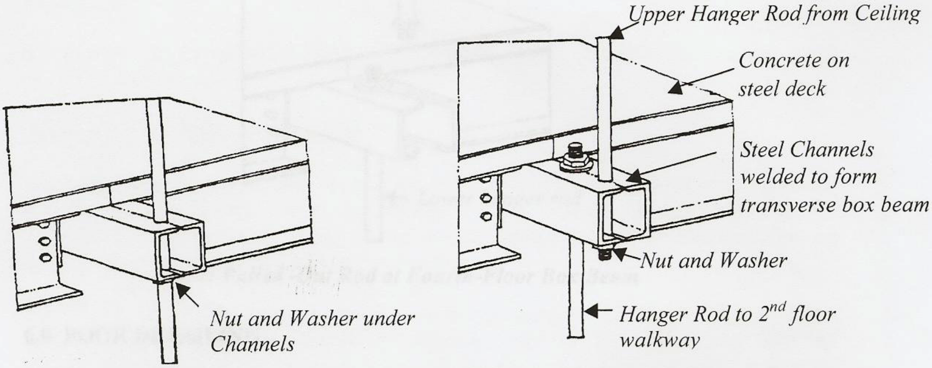


Fig. 5(a): Hyatt Regency Hanger Details As-Designed

Fig. 5(b): Hyatt Regency Hanger Details As-Built

As designed, each of the two skywalks hangs onto the rope with its own hands. As built, the lower skywalk's hands are effectively hanging onto the upper skywalk's feet! So the upper skywalk's grip on the rope feels $2\times$ larger force than in original design. Oops!

A real-world use for free-body diagrams! But these diagrams aren't careful to single out one object, to indicate clearly what that object is, and to draw only the forces acting ON that object. (Alas.)

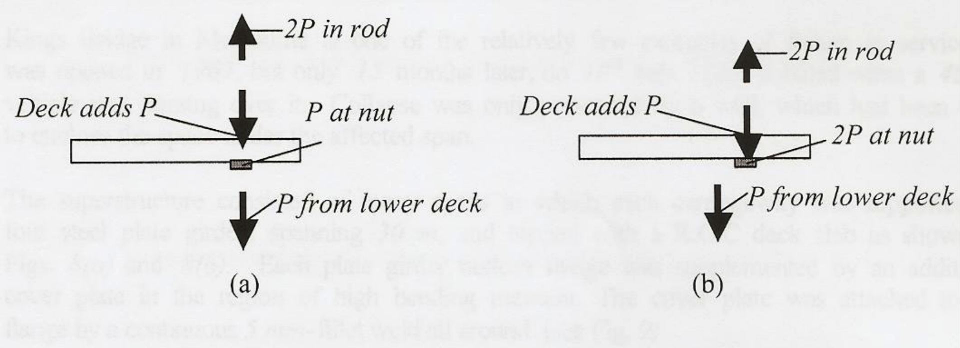


Fig. 6: Free-Body Diagram (a) As Designed (b) As Built

The author uses the symbol P for a "point" force (or point load, or a "concentrated load"), as is the custom in engineering and architecture. When you see "P" here, pretend it says "F" or "mg" instead.

Upper skywalk loses its grip on the "rope"

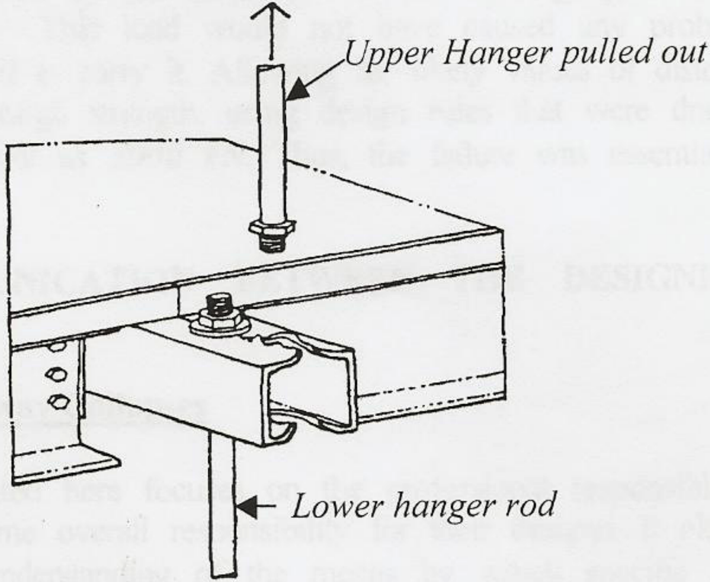


Fig. 7: Pulled -Out Rod at Fourth-Floor Box Beam

Ch9: work. Two definitions of work

- Work equals the change in energy of a system due to external forces. If the energy of a system increases, the (arithmetic sum of) work done by external forces on the system is positive; if the energy of a system decreases, the (sum of) work done by external forces on the system is negative.

$$\Delta E_{\mathrm{system}} = W_{\mathrm{done\ ON\ system}}$$

- The work done by an external force $\vec{F}$ on a system (in one dimension) is $\boxed{W = \int F_x(x)\,\mathrm{d}x}$ or just $\boxed{W = F_x\,\Delta x}$ for a constant force. When the force and the "displacement of the point of application of the force" point in the same (opposite) direction, the work done by $\vec{F}$ is positive (negative).

Let's initially focus on the second, more familiar, definition.

Chapter 9: first reading question

1. If you graph the work, $W(x)$, done by a force on an object as a function of the object's position, x, what graphical feature represents the force, $F(x)$, exerted on the object?

(A) The force is the area under the work curve.

(B) The force is the slope of the work curve.

(C) The vertical axis, i.e. the height of the work curve.

(D) The second derivative.

Chapter 9: first reading question

1. If you graph the work done by a force on an object as a function of the object's position, what graphical feature represents the force exerted on the object?

Since work equals the integral of force w.r.t. displacement, $W = \int F_x \mathrm{d}x$ or $W = F_x \Delta x$, the force is equal to the work per unit displacement. On a graph of W vs. x, the slope, $\mathrm{d}W/\mathrm{d}x$, is equal to the force.

Suppose you want to ride your mountain bike up a steep hill. Two paths lead from the base to the top, one twice as long as the other. (Your bicycle has only one gear.) Compared to the average force you would exert if you took the short path, the average force you exert along the longer path is

(A) one-fourth as large.

(B) one-third as large.

(C) one-half as large.

(D) the same.

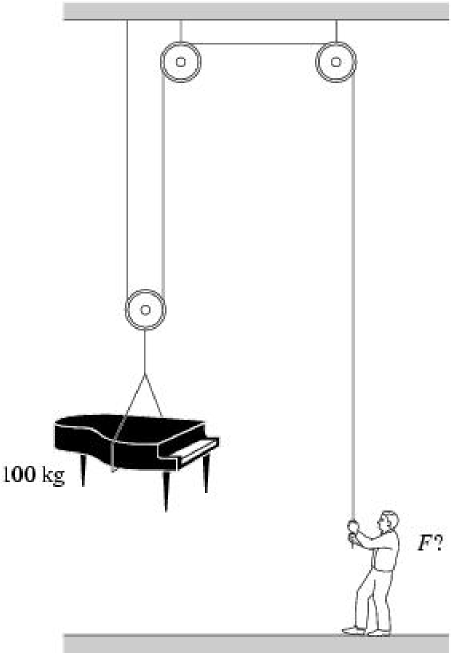
(E) twice as large.

(F) undetermined — it depends on the time taken

(Imagine how hard you have to press down on the pedals, on average, to make the bike go up one path vs. the other. As a kid, did you ever zig-zag up a really steep hill on your one-speed bike, or if your multi-speed bike's lowest gear was still not low enough?)

Imagine me towing Alfie up a steep hill behind my bicycle . . . .

https://youtu.be/Yigqi7zGCfQ
https://youtu.be/ewvet0I1YiM



A piano mover raises a 100 kg piano at a constant speed using the pulley system shown here. With how much force is she pulling on the rope? (Ignore friction and assume $g \approx 10\ \mathrm{m/s^2}$.)

(A) 2000 N

(B) 1500 N

(C) 1000 N

(D) 750 N

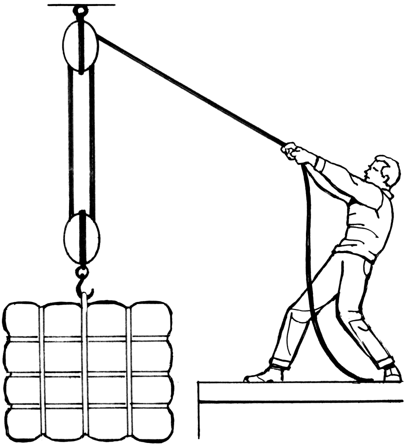
(E) 500 N

(F) 200 N

(G) 50 N

(H) impossible to determine.

Block and tackle: "mechanical advantage"



This graphic shows a 2:1 mechanical advantage. The block & tackle in the classroom shows a 4:1 advantage. How would you get a HUGE mechanical advantage, like 1000:1 ? (Phys 009 topic.)

A spring-loaded toy dart gun is used to shoot a dart straight up in the air, and the dart reaches a maximum height of 8 m. The same dart is shot straight up a second time from the same gun, but this time the spring is compressed only half as far before firing. How far up does the dart go this time (neglecting friction)?

(A) 1 m

(B) 2 m

(C) 4 m

(D) 8 m

(E) 16 m

(F) 32 m

(We used the last 2 minutes of class to ponder this question.)

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

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

- $W = 0$

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

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

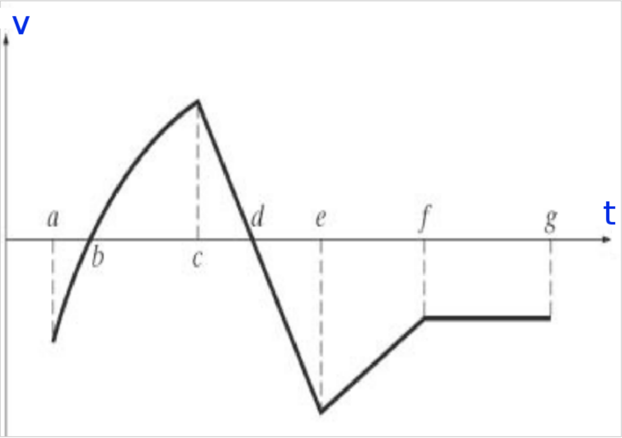
When you stand up from a seated position, you push down with your legs. Does this mean you do negative work when you stand up?

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."

2. The velocity of an object as a function of time is shown in the figure below. Over what intervals is the work done on the object (a) positive, (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.)

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.:

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

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

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 $-\frac{\mathrm{d}U_{\mathrm{spring}}}{\mathrm{d}x}$):

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

A spring-loaded toy dart gun is used to shoot a dart straight up in the air, and the dart reaches a maximum height of 8 m. The same dart is shot straight up a second time from the same gun, but this time the spring is compressed only half as far before firing. How far up does the dart go this time (neglecting friction)?

(A) 1 m

(B) 2 m

(C) 4 m

(D) 8 m

(E) 16 m

(F) 32 m

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

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

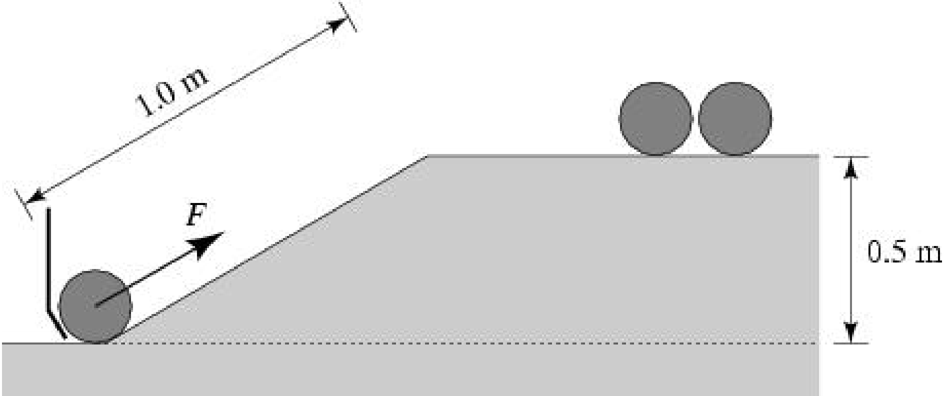
(C) 2

(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. During the time interval while the rock is slowing to a stop (as the rock is hitting the ground), 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.

Physics 8 — Friday, September 27, 2019

- Turn in HW#4. Pick up handout for HW#5, which covers Ch9 and starts Ch10.
- For Monday, finish reading Ch10 (motion in a plane).
- If you have little or no coding experience and you're interested in an XC option to learn Python for quantitative tasks like graphing and modeling data, email me ASAP.
- Wolfram Mathematica is free (site license) for SAS and Wharton students. I have some very helpful self-study Mathematica materials you can do for XC. Email if interested.
- If you're interested in learning to do a bit of Python coding in a drawing/animation system called "Processing" made by and for visual artists, you can look at my Fall 2017 day-before-Thanksgiving lecture here: `http://xray.hep.upenn.edu/wja/p008/2017/files/phys8_notes_20171122.pdf`