PHY131 F Fall 2020
Class 19

Today:

6.7 Collisions in 2D

7.1 Work and Energy

7.2 Conservation of Energy

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Poll Question (Ch.6 Review)

- A 1.0 kg block is dropped from a height of 1.0 m above the floor.
- When it collides with the floor, it takes 1.0 ms to come to a complete stop (inelastic collision). $\Delta t = 1.0 \times 10^{-3}$ s
- What was the magnitude of the average force of the floor on the block during the collision?

A. 2.2 N

B. 4.4 N

C. 1100 N

D. 2200 N

E. 4400 N

2 segments: (1) Free fall a distance h at $a = 9.8$ m/s^2
(2) Collision with floor $\Delta t = 10^{-3}$ s

Seg. 1
Use Eq. 2.7 $2ah = v_{f1}^2 - v_{i1}^2$
$v_{i1} = 0$ (Assume dropped from rest).
$v_{f1} = \sqrt{2gh} = \sqrt{2(9.8)1.0}$
$v_{f1} = 4.43$ m/s

Seg. 2 $v_{f1} = v_{i2} = 4.43$ m/s Define $+y$ = down.
$p_{iy} + J_y = p_{fy} = 0$
$m v_{i2} + F_y \Delta t = 0$
$|F_y| = \frac{m v_{i2}}{\Delta t} = \frac{1.0(4.43)}{1 \times 10^{-3}} = 4400$ N

2

A yellow Hummer (m_H = 3900 kg) was driving South and collided with a blue Toyota (m_T = 1200 kg) which was driving East. The speed limit on both roads is 50 km/hr.

After the collision, the two cars stuck together and the combined mass skidded along the ground.

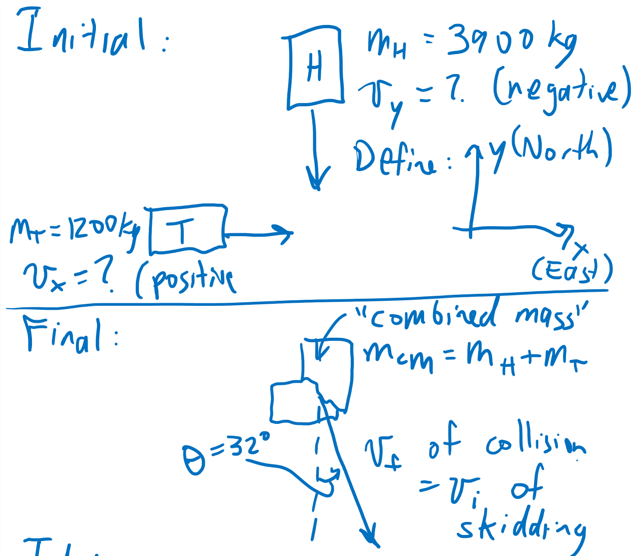
The police measure that the skid marks are a line 10 m long, angled 32° East of South.

The coefficient of kinetic friction between rubber and road is 0.8.

How fast were the cars going before the collision? Who is at fault?

SKETCH & TRANSLATE.

Assume no external impulse during collision. $\vec{p}_i = \vec{p}_f$



Idea

Kinetic friction causes the combined mass to slow as it skids v_i $d = 10$ m $v_f = 0$

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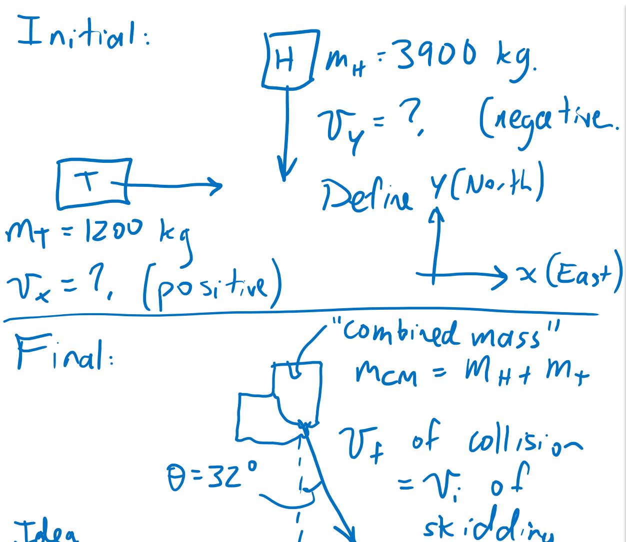


Idea

Kinetic friction causes the combined mass to slow as it skids: v_i $v_f = 0$ $d = 10$ m

How fast were the cars going before the collision? Who is at fault?

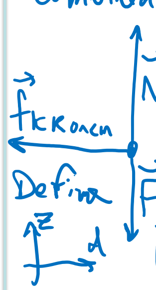
SIMPLIFY & DIAGRAM

2 segments of motion: (1) Collision (2) skidding.

v_f of (1) $= v_i$ of (2)

Let's start by analyzing Seg (2):

Force diagram of combined mass:



$\Sigma F_z = 0 = N - m_{cm} g$

$N = m_{cm} g$

$\Sigma F_d = -\mu_k N = -\mu_k m_{cm} g$

$a_d = \frac{\Sigma F_d}{m_{cm}} = -\mu_k g$

Use Eq. 2?: $2 a d = v_f^2 - v_i^2$ ($v_f \to 0$)

$v_i = \sqrt{-2 a_d d} = \sqrt{2 \mu_k g d}$

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How fast were the cars going before the collision? Who is at fault?

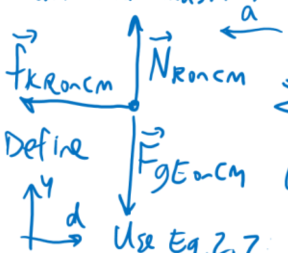
SIMPLIFY & DIAGRAM

2 segments of motion: ① Collision.
② Skidding.

v_f of ① = v_i of ②

Let's start by analyzing seg ②:

Force diagram of combined mass.



$\sum F_y = 0 = N - m_{cm} g$

$\Rightarrow N = m_{cm} g$

$\sum F_d = -\mu_k N = -\mu_k m_{cm} g$

$a_d = \frac{\sum F_d}{m_{cm}} = -\frac{\mu_k m_{cm} g}{m_{cm}}$

Use Eq. 2.7 $\quad 2ad = v_f^2 - v_i^2$ ($v_f^2 = 0$)

$v_i = \sqrt{-2a_d d} = \sqrt{2\mu_k g d}$

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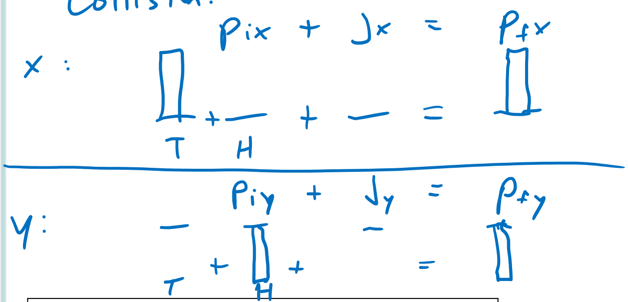
Collision:



REPRESENT MATHEMATICALLY

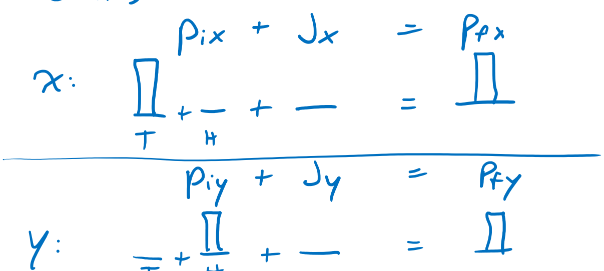
x: $\quad m_T v_{Ti} + 0 + 0 = m_{cm} v_f \sin\theta \quad (1)$

y: $\quad 0 - m_H v_{Hi} + 0 = -m_{cm} v_f \cos\theta \quad (2)$

(1)⇒ $\quad v_{Ti} = \frac{m_{cm}}{m_T}\sqrt{2\mu_k g d}\,\sin\theta$

(2)⇒ $\quad v_{Hi} = \frac{m_{cm}}{m_H}\sqrt{2\mu_k g d}\,\cos\theta$

Collision:



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(1)⇒ $\quad v_{Ti} = \frac{m_{cm}}{m_T}\sqrt{2\mu_k g d}\,\sin\theta$

(2)⇒ $\quad v_{Hi} = \frac{m_{cm}}{m_H}\sqrt{2\mu_k g d}\,\cos\theta$

SOLVE & EVALUATE

$v_{Ti} = \frac{1200 + 3900}{1200}\sqrt{2(0.8)9.8(10)}\,\sin 32$

$v_{Ti} = 28.2\ m/s$

$v_{Hi} = \frac{1200 + 3900}{3900}\sqrt{2(0.8)9.8(10)}\cdot\cos 32$

$v_{Hi} = 13.9\ m/s$

The Toyota was going much faster than the Hummer.

$v_{Ti} = 28.2\frac{m}{s}\left(\frac{60\ s}{1\ min}\right)\left(\frac{60\ min}{1\ hr}\right)\left(\frac{1\ km}{1000\ m}\right)$

$v_T = 102\ \frac{km}{h}$ ← in a 50 km/h zone.

Toyota is at fault!

6

What's the Big Idea?

- Chapters 6 and 7 introduce the principles of **conservation of momentum** and **conservation of energy**. These concepts give us new useful ways of analyzing motion.
- Some quantities stay the same while other things around them change.
- For example, when a dish falls to the floor and shatters, the initial mass of the plate should equal the total final mass of all the pieces. This is "Conservation of Mass": $M_i = M_f$.
- Similarly, we have "Conservation of Momentum" ($\vec{p}_i = \vec{p}_f$), and "Conservation of Energy" ($E_i = E_f$): two new principles which we will use to solve problems.

7

What is "energy"?

- Energy is a property of an object, like age or height or mass.
- Every object that is moving has some Kinetic Energy K.
- An object in a gravitational field also has some Gravitational Potential Energy U_g.
- Energy has units, and can be measured. ← SI units are "Joules"
- Energy is *relative*; kinetic energy of car is different for an observer in the car than it is for an observer standing on the side of the road.

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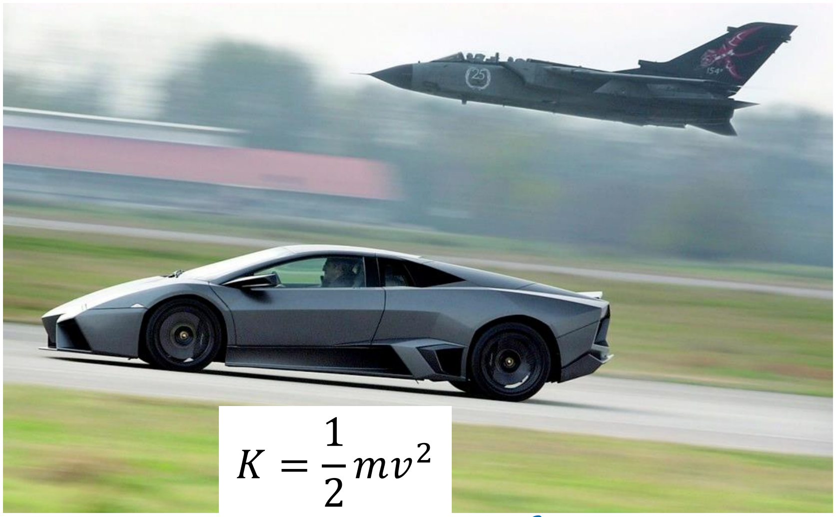
Kinetic Energy: The energy of ***motion***

Units:

$kg \cdot \frac{m^2}{s^2}$

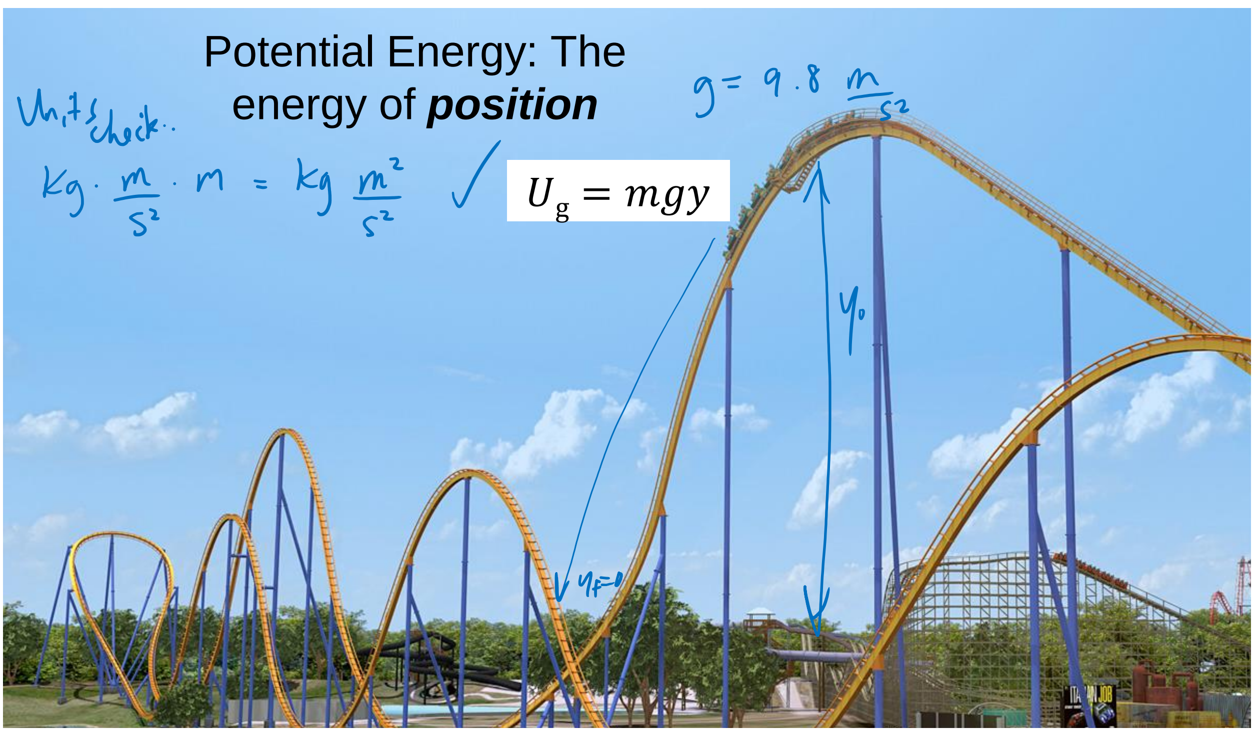
= "Joule"



$$K = \frac{1}{2}mv^2$$

v = speed.

Potential Energy: The energy of ***position***



Units check..

$kg \cdot \frac{m}{s^2} \cdot m = kg \frac{m^2}{s^2}$ ✓

$$U_g = mgy$$

$g = 9.8 \frac{m}{s^2}$

y_0

$y_f = 0$

Potential Energy: The energy of ***position***

S = spring

$$U_s = \frac{1}{2}kx^2$$

k = "spring constant"

x = distance the end of spring is pushed or pulled past "equilibrium"

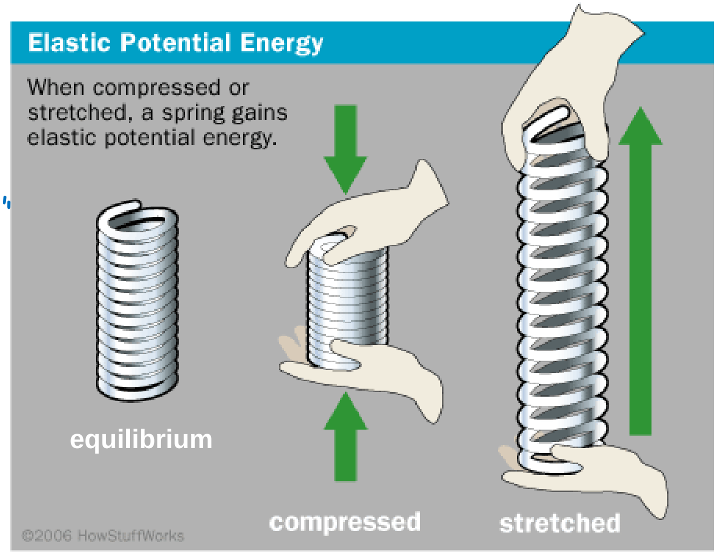


Image from https://energyeducation.ca/encyclopedia/Elastic_potential_energy

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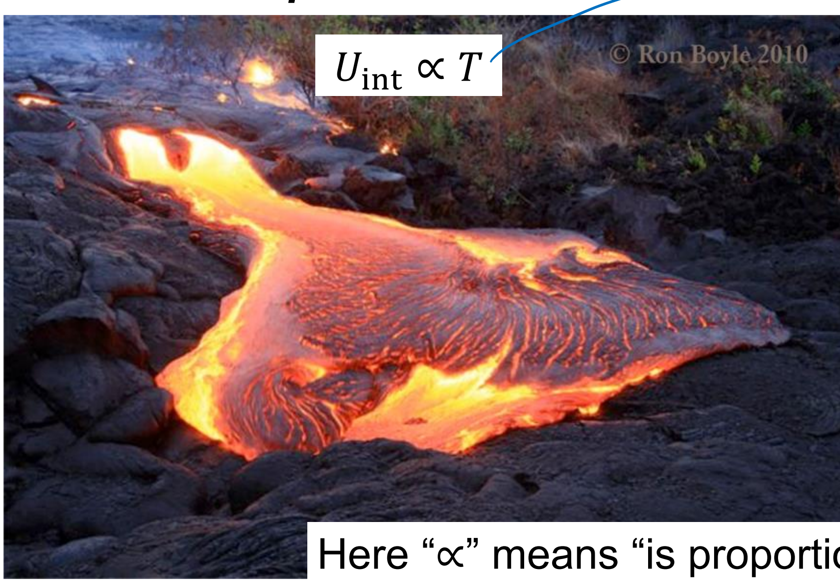
Internal Energy: The energy of ***microscopic thermal vibrations***



$$U_{\text{int}} \propto T$$

This proportionality works for T in degrees Kelvin

Here "∝" means "is proportional to"

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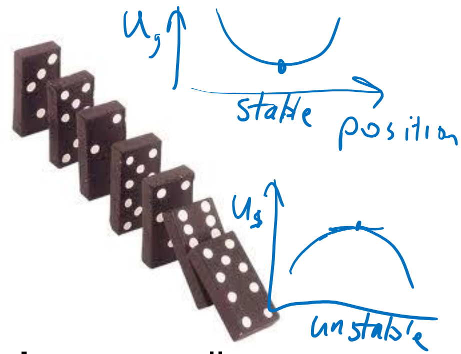
Dominoes

- A domino is a rectangular solid which can be balanced on its edge
- When standing upright, its gravitational potential energy is a maximum



- This is a state of **unstable equilibrium**: a small perturbation can cause the domino to fall, transforming its gravitational potential energy into kinetic energy
- As it is falling, it can perturb its neighbor, which then releases its potential energy: a ***chain reaction*** can ensue!

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The most basic form of energy: **Work**

- involves force and distance.
- is force × distance.
- in equation form: $W = F\, d \cos\theta$
- Here θ is the angle between the force and displacement

$F = ma$

units:

$N = kg \cdot \frac{m}{s^2}$

$N \cdot m = kg \frac{m^2}{s^2}$ ✓

Two things occur whenever work is done:

- application of force
- movement of something by that force

SI Unit of work: newton-meter (N·m) or joule (J)

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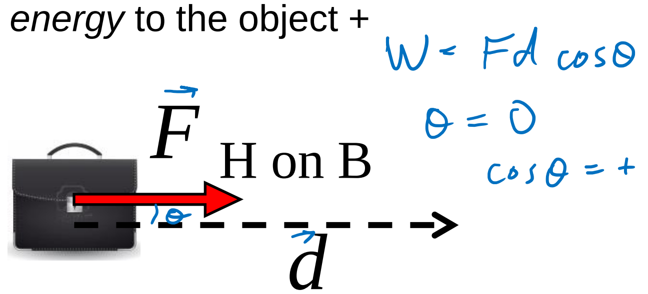
Work can be positive, zero or negative

- Your hand (H) pulls a briefcase (B) to the right and it moves to the right.
- When the force and the distance are in the *same* direction, you are *helping* the motion with the force, so the work done on the object is **positive**.
- The force is *adding energy* to the object + environment.

- Maybe this force is speeding the object up.



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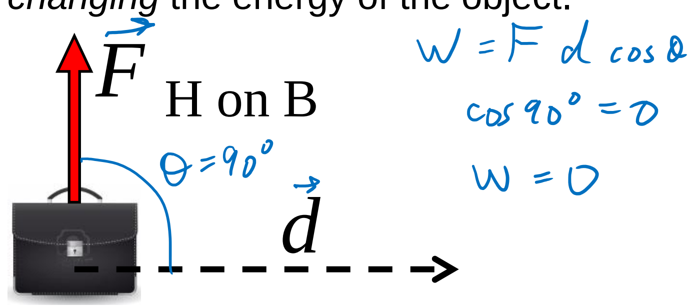
Work can be positive, zero or negative

- Your hand (H) supports a briefcase (B) with an upward force, as the briefcase moves to the right.
- When the force and the distance are *at right angles*, you are *not* helping the motion with the force, so the work is **zero**.
- This force is *not changing* the energy of the object.

- This force won't speed the object up or slow it down.



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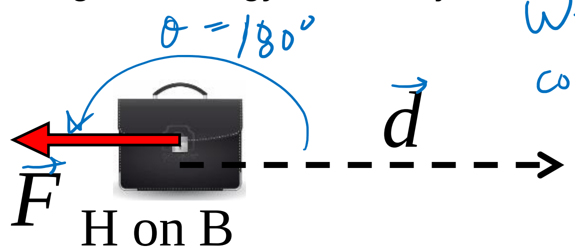
Work can be positive, zero or negative

- Your hand (H) pulls a briefcase (B) to the left, while, for some reason, the briefcase moves to the right.
- When the force and ~~distance~~ displacement are in *opposite* directions, you are *hindering* the motion with the force, so the work done on the object is **negative**.
- This force is *reducing* the energy of the object.
- Maybe this force is slowing the object down.



$W = Fd\cos\theta$

$\cos 180° = -1$

$W = -Fd$

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Poll Question

- Justin is doing a bench press, and he slowly pushes the bar up a distance of 0.30 m while pushing upwards on the bar with a force of 200 N. The bar moves with a constant velocity during this time.
- During the upward push, how much **work** does Justin do on the bar?

  A. 60 J
  B. 120 J
  C. 0 J
  D. -60 J
  E. -120 J

$\vec{F}_{J on B}$ $\vec{d}$ $\theta = 0$

$W = Fd = (200\ N)(0.3\ m) = 60\ J$

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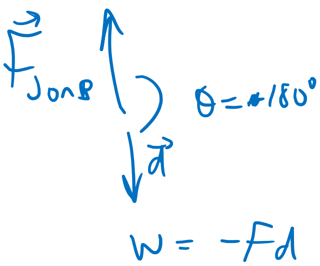
Poll Question

- Justin is doing a bench press, and he slowly lowers the bar down a distance of 0.30 m while pushing upwards on the bar with a force of 200 N. The bar moves with a constant velocity during this time.
- During the downward lowering, how much **work** does Justin do on the bar?



A. 60 J
B. 120 J
C. 0 J
D. -60 J
E. -120 J

Poll Question

- Justin is doing a bench press, and he slowly lowers the bar down a distance of 0.30 m while pushing upwards on the bar with a force of 200 N. He then pushes it up slowly the same distance of 0.30 m back to its starting position, also pushing upwards on the bar with a force of 200 N.
- During the complete downward and upward motion, how much total **work** does Justin do on the bar?

A. 60 J
B. 120 J
C. 0 J
D. -60 J
E. -120 J

Midterm Assessment #3

- Each online half-hour assesement is worth between 10% and 12.5% of your mark in this course.
- The lowest of five assessment scores will be dropped.
- The assessment will become available on Quercus to start at 8:10pm tomorrow evening, Toronto time (ie 32 hours from right now)
- If you are registered for the alternate sitting, then you do the whole thing exactly 2 hours later.
- If you miss the assessment, you get a zero.

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Midterm Assessment #3

- The assessment is "open book"; allowed aids include your course notes, the textbook, videos, google-searches for static web-pages, a calculator, Excel, Python, etc.
- You must work on the assessment **individually**.
- No group work or chats with other students are allowed during the assessment.
- Once you start there will be a 30-minute timer
- The assessment ends when your personal 30-minute timer elapses, or 8:45pm, whichever comes *first*.

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Midterm Assessment #3

- You will see one question at a time, in a random order.
- You must submit each answer by clicking Next in order to see the next question; you will **not** have the ability to go back change any answer after it has been submitted.
- After completing all 10 questions you must click Submit Quiz before the time has ended.
- There are 4 conceptual questions and 6 numerical questions.
- You **will** need a calculator, or Excel or something to do these. You should have pencil and paper ready for rough work.

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Midterm Assessment #3

- All questions are Multiple Choice, marked automatically.
- The average time per question is 3 minutes, but numerical questions will likely take longer than conceptual, so do not linger long on the conceptual questions.
- Material will cover mostly questions and problems from Chapters 5 and 6 from Etkina. Chapters 2-4 are also important to remember, but are not specifically tested in this assessment.
- There will be at least one question based on your work in Practicals 2a and b and 3a.

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Before Class 20 on Wednesday

- Please read:
- 7.3 Kinetic Energy, Gravitational Potential Energy
- 7.4 Elastic Potential Energy
- 7.5 Work of Sliding Friction

- Good luck on tomorrow’s test! 24 + 8 hours from right now!

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