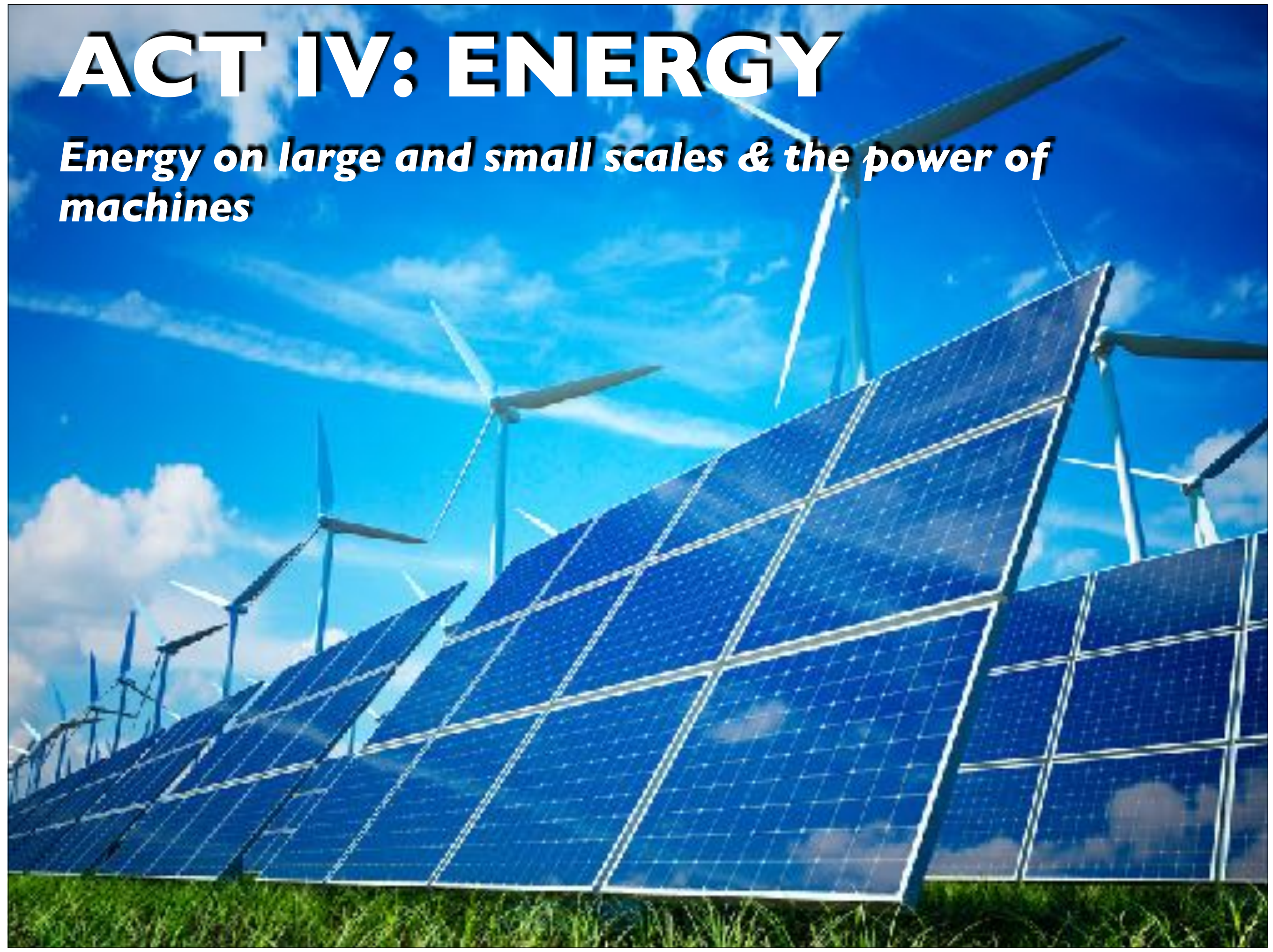
ACT IV: ENERGY

Energy on large and small scales & the power of machines




SCENE I:
MACRO-SCALE
ENERGY
The Energy We Can
See in Action

What comes to mind when you think of energy?

Energy is the ability to do stuff

- Before we looked at force as playing the central role in determining motion
- But we can also analyze motion by looking at energy

ENERGY IS…

- Scalar (direction doesn't matter)
- Conserved (energy can't be created or destroyed, just shuffled around)
- Measured in a unit called a joule (J)

FORMS OF ENERGY

- kinetic or mechanical
- gravitational
- elastic
- heat
- chemical
- electrical
- nuclear
- mass

WORK

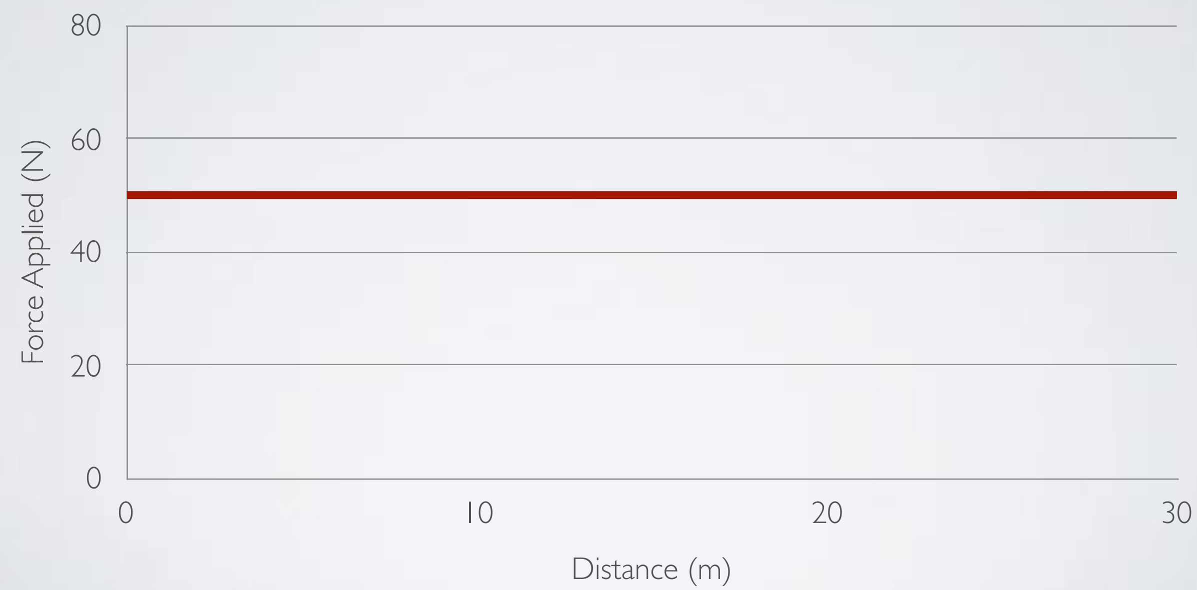
In physics, work is the energy needed to enact a force through some displacement

- Your mom's rearranging the living room and asks you move the couch to the other side of the room
    - Nbd
- Your family's moving, and your mom asks you to move the couch into the moving van
    - Giant pain in the butt

$$W = \int F \bullet dr$$

work *equals* ***force*** *integrated over* ***distance***

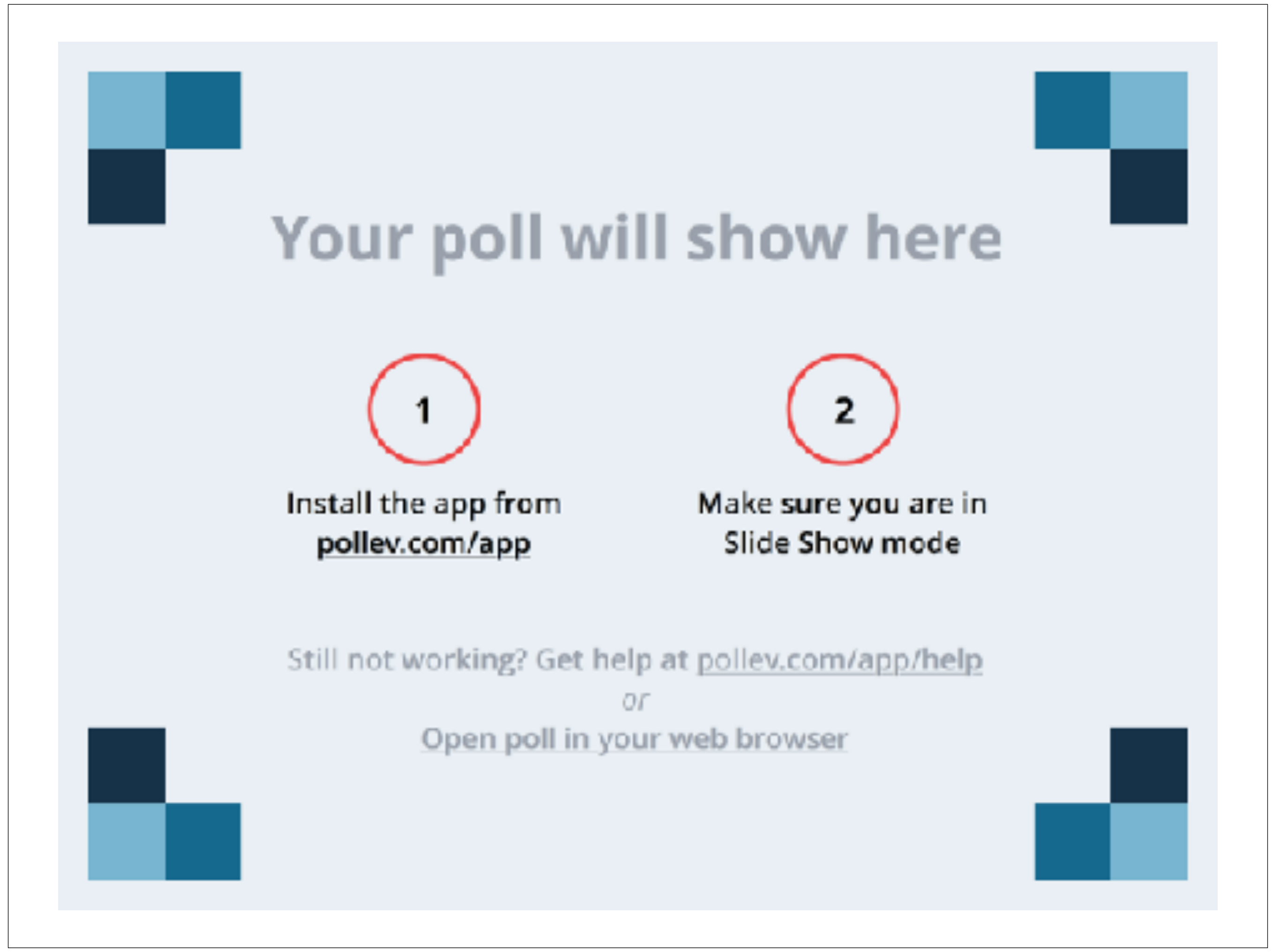
- Ex. You apply 50 N of force horizontally to move a grocery cart 30 m. How much work did you do?



- To calculate the work done, find the area under the *force vs distance* graph
- 50 N x 30 m = 1500 J

WORK

A force can be exerted on an object and yet do no work



Which of the following does work?
https://www.polleverywhere.com/multiple_choice_polls/W2tEas7lCnJbMxi

Which of the following does work?

A. Holding a heavy bag of groceries

B. A large asteroid drifts 20 km at a constant speed

C. Lifting a mug of hot chocolate to your mouth

D. Gravity on a couch as you push it across the room

Which of the following does work?

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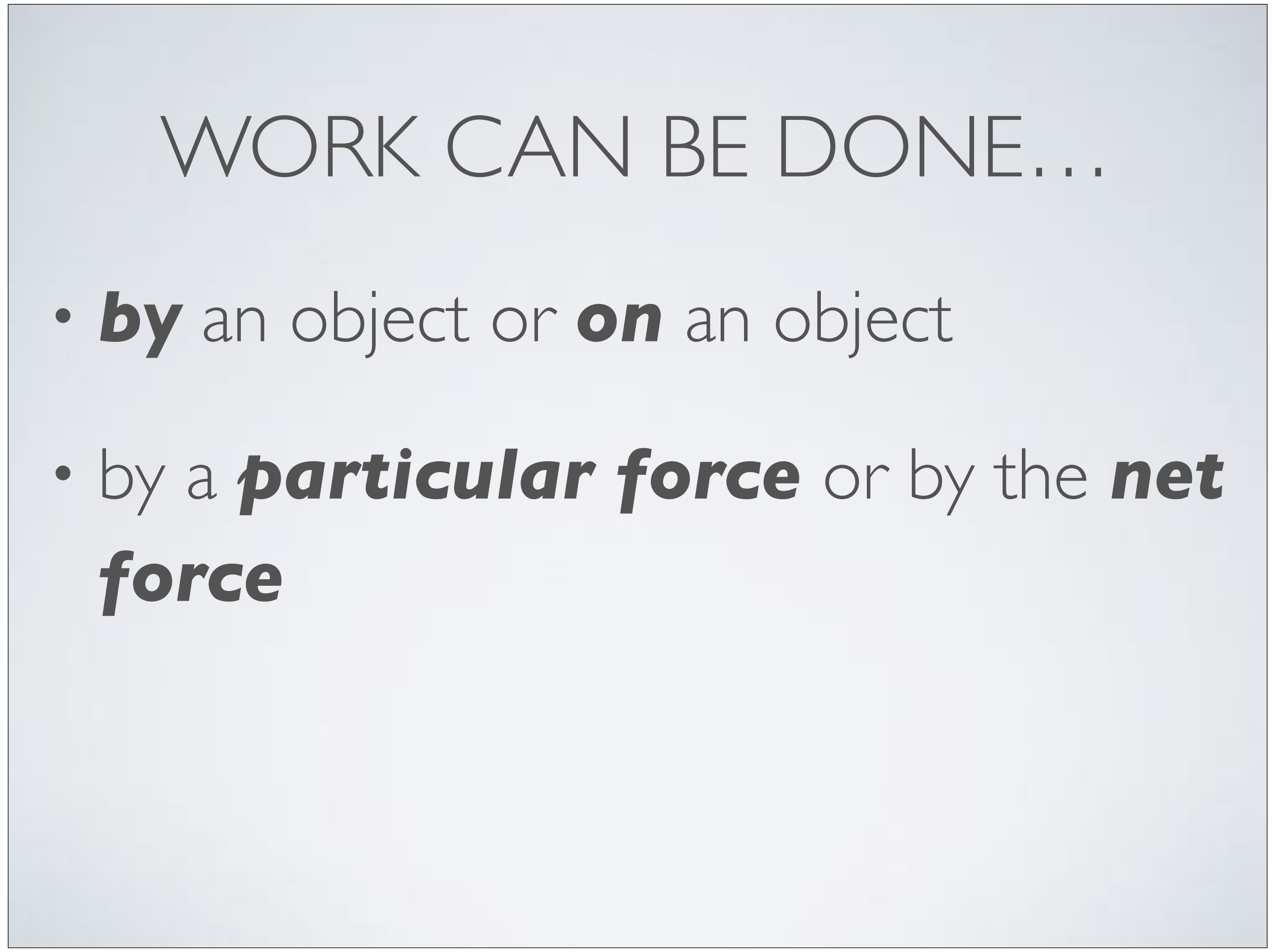
D. Gravity on a couch as you push it across the room

The only forces that do work are the ones that **contribute to motion**


WORK CAN BE DONE…
• by an object or on an object
• by a particular force or by the net force

- Be specific!

PRACTICE I: CAN I PAY YOU IN NICKELS?

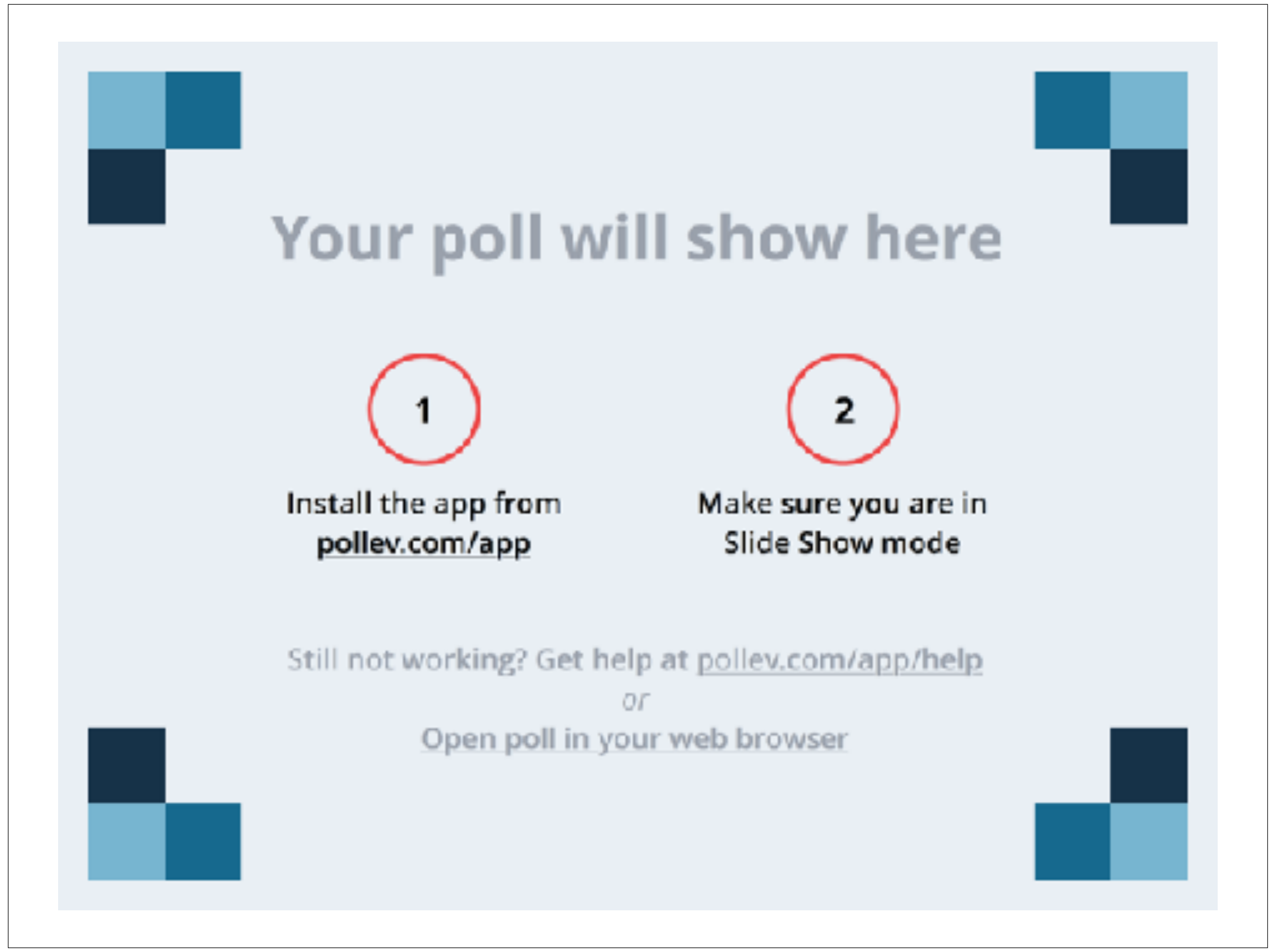
- You demanded your job pay you in nickels, and now you have to drag a box of your bi-weekly paycheck to your car
- You drag the 50 kg crate 40 m across the floor by applying a constant force, F_A = 100 N. The floor is rough and exerts a friction force F_{fr} = 40 N
- Determine the work done by each force acting on the crate and the net work done on the crate

- Answer: $W_g = 0$
- $W_N = 0$
- W_A = 4,000 J
- W_{fr} = -1,600 J
- W_{net} = 2,400 J

NEGATIVE ENERGY

- Forces done *against* motion do negative work
- Energy put into the system is positive, energy taken out of the system is negative

- In the last problem, friction did negative work because it takes energy out of the system (and converts it to heat energy)



The Moon revolves around the Earth in a circular orbit, kept there by the gravitational force exerted by the Earth. What work does gravity do on the Moon?
https://www.polleverywhere.com/multiple_choice_polls/1QN8iPfWvHv3fkw

The Moon revolves around the Earth in a circular orbit, kept there by the gravitational force exerted by the Earth. What work does gravity do on the Moon?

A. positive work

B. negative work

C. no work at all

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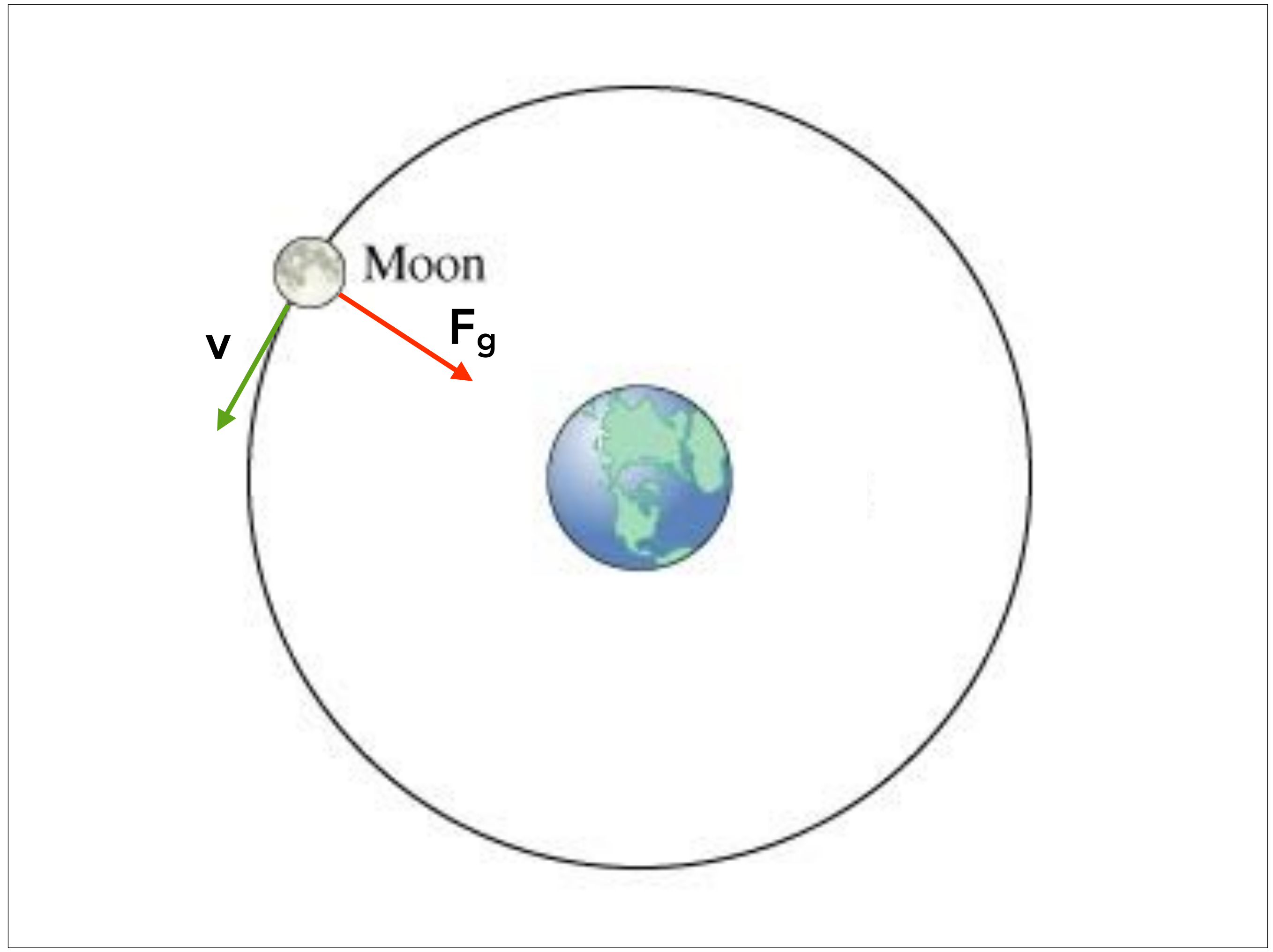
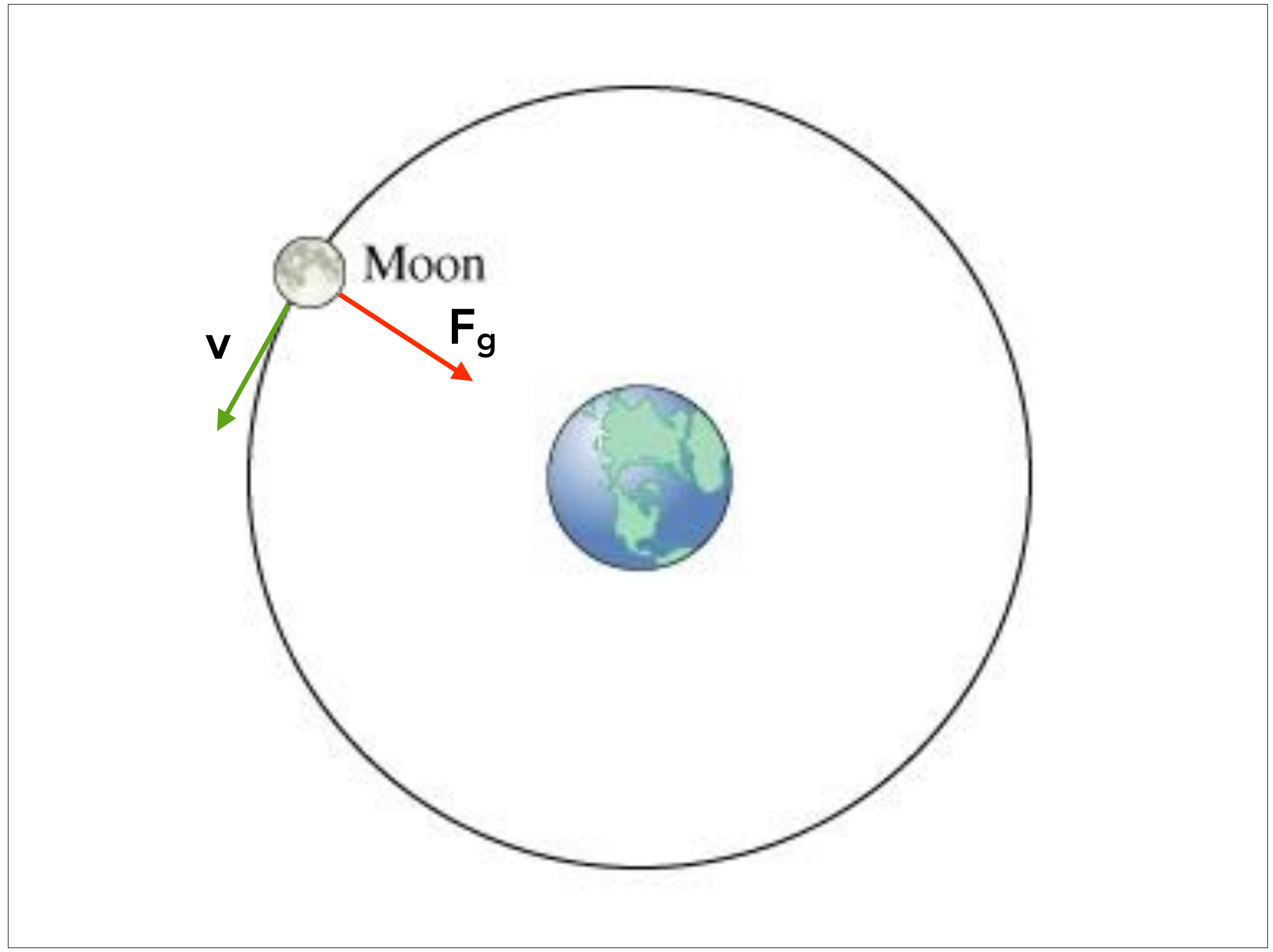

Moon
v
F_g



- No component of the force of gravity acts in the same direction as the Moon’s motion, therefore gravity doesn’t do any work on the Moon


headlikeanorange

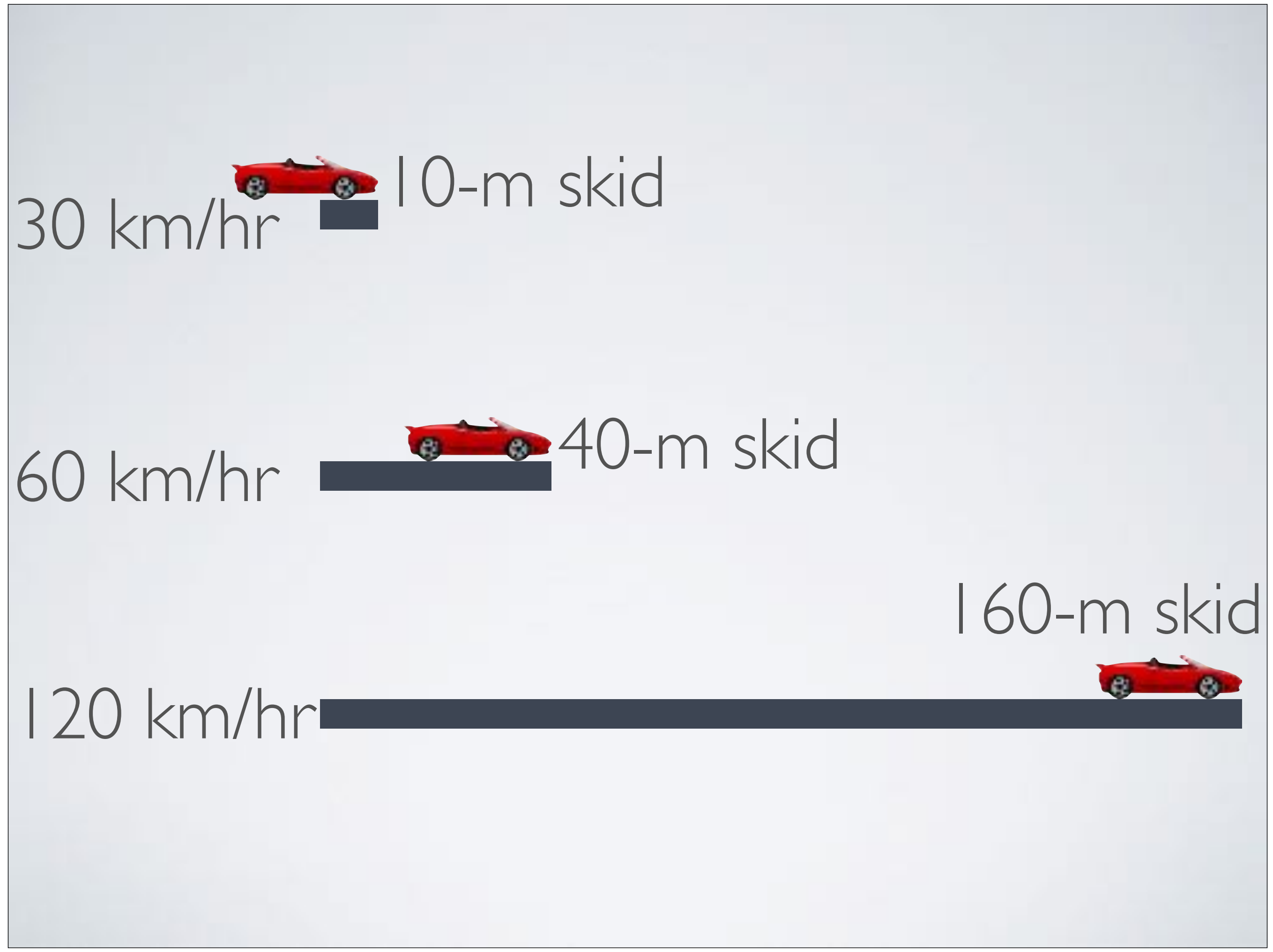
Kinetic Energy is the energy of motion

- The kinetic energy of an object depends on the mass of the object as well as its speed

$$KE = \tfrac{1}{2}mv^2$$

the ***kinetic energy*** *of an object equals half the object's* ***mass*** *multiplied by the square of its* ***speed***

- The kinetic energy of a moving object is equal to the work required to bring up to that speed from rest (or, equivalently, the work the object can do while being brought back to rest)
- net force × distance = kinetic energy
- $Fd = \tfrac{1}{2}mv^2$

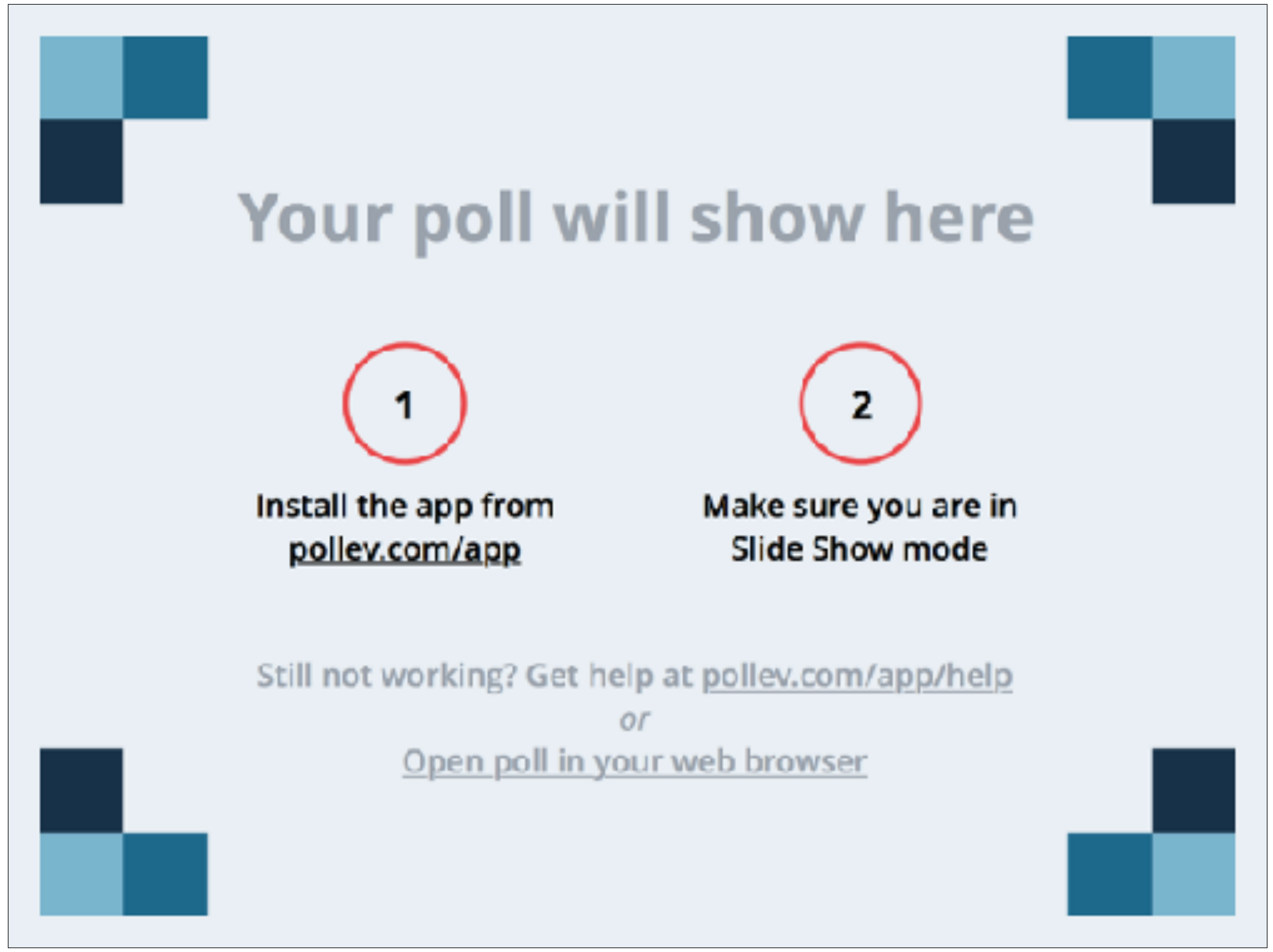


- Notice that speed is squared, so doubling the speed *quadruples* the kinetic energy!
- It takes four times the work to double the speed and takes four times the stopping distance to bring it to a halt

$$W_{net} = \Delta KE$$

*the **net work** done on an object is equal to the **change** in its **kinetic energy***

- Net work tells you how much energy is being put into or taken out of a system
- Put energy into a system, and it speeds up. Take energy out, and it slows down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An object initially has kinetic energy KE. If its mass is halved, what happens to its kinetic energy? Kinetic energy is

A. halved

B. quartered

C. stays the same

D. doubled

E. quadrupled

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PRACTICE II: GOTTA CATCH 'EM ALL!

- Ash Ketchum, objectively the world's worst Pokémon trainer, throws a 145 g pokéball with a speed of 25 m/s.

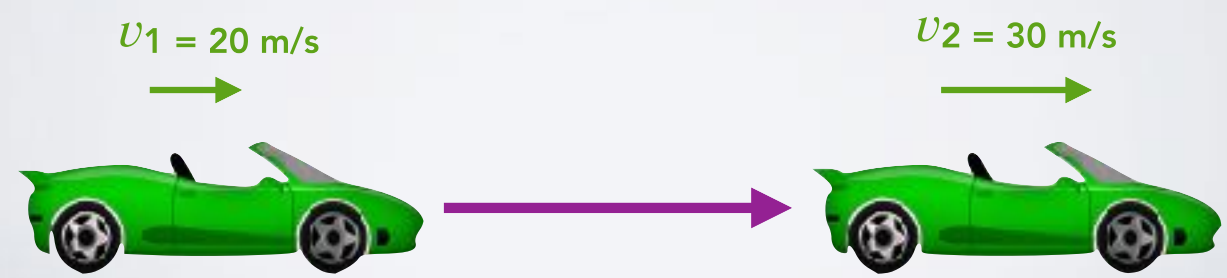
a. What is the pokéball's kinetic energy?

b. How much work was done on the ball to make it reach this speed if it started from rest?

- Ans. KE = 45 J
- W_{net} = 45 J

PRACTICE III: THE COST OF SPEED

How much work is required to accelerate a 1000 kg car from 20 m/s to 30 m/s?



- Ans. $W = 2.5\times10^5$ J

Potential Energy is the energy of position or configuration

- E.g. When you wind a clock, you do work on the clock and thus put energy into the system, which it then releases over time
- You can think of potential as stored energy — it is energy the object has the *potential* to use

- When you put yourself in the position of some height, you have the potential to fall and gain kinetic energy
- How much kinetic energy you gain depends how high up you are and how strong the gravity is

PRACTICE IV: DOGGO

- You lift a puppy with mass *m* from the ground to a height *h*.
- If you lift the pup at a constant velocity, how much work did you do picking it up?

- Ans. $W_A = mgh$

$$PE_g = mgh$$

*the **gravitational potential energy** of an object is equal to the product on the object's **weight** and its **height***

- It's worth asking, "Height above (or below) what, exactly?"

- The two vases are the same height above the floor, but that fact isn't equally relevant to both of them
- When we talk about the object's "height," it can be the height above or below any reference point you want
- It's the *change* in potential energy that has physical meaning since that's what's related to the work done

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You and your friend (both mass m) need to get to the third floor of a the high school. You run up the stairwell while your friend takes the elevator. Who has the greater gravitational potential energy when you both reach the top?

A. You

B. Your friend

C. Both will be the same

D. Need more information

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A. You

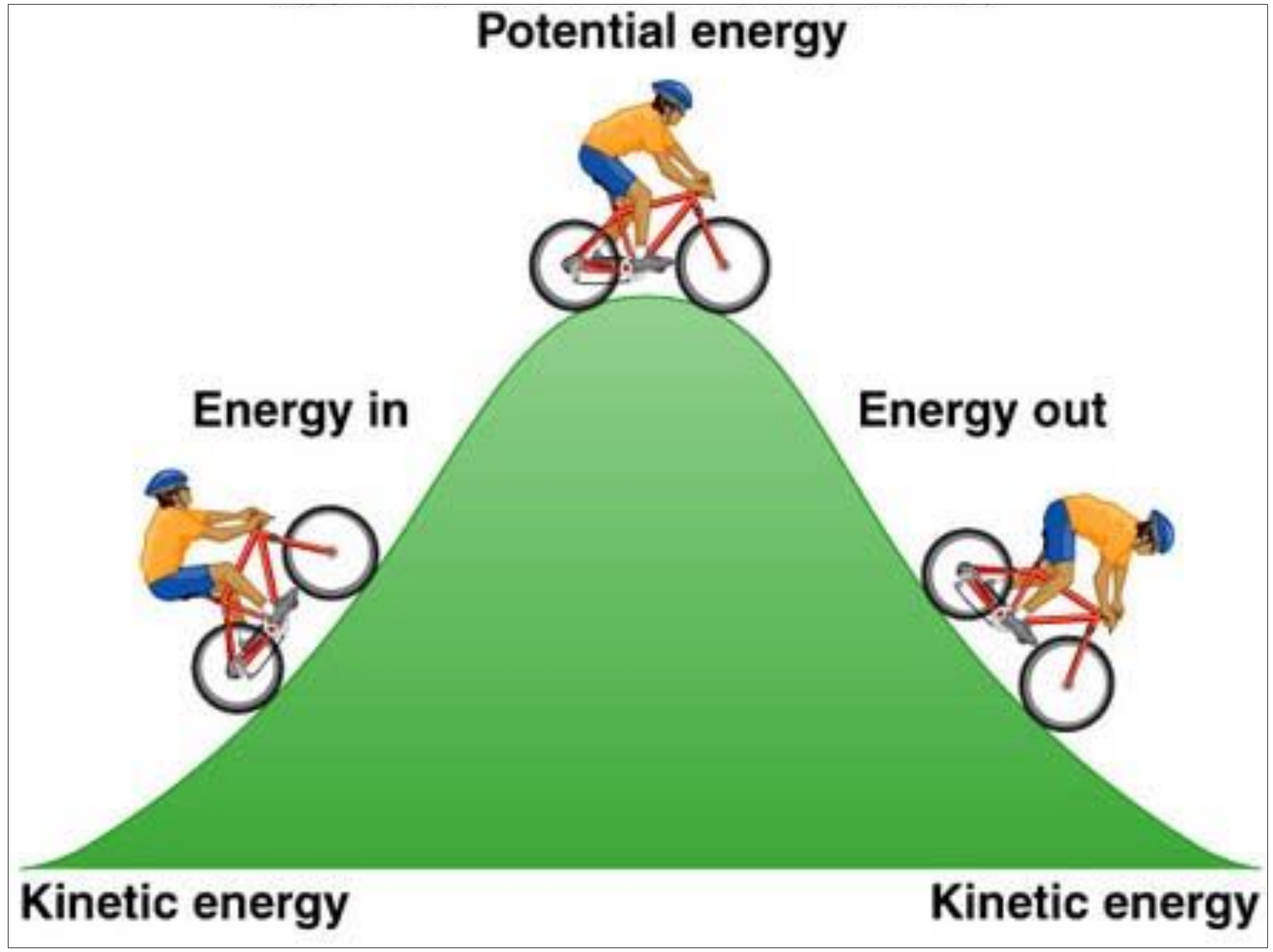
B. Your friend

C. Both will be the same

D. Need more information

POTENTIAL ENERGY IS INDEPENDENT OF THE PATH TAKEN

- Potential energy may be the energy of position, but it doesn’t matter how you got to that position

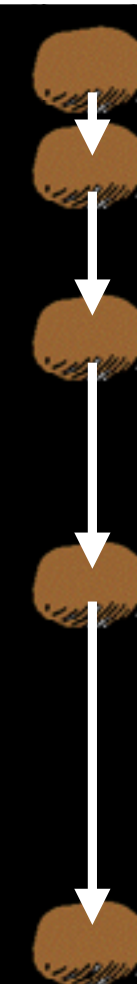


- When an object falls, it will never hit the ground with more energy than it started with

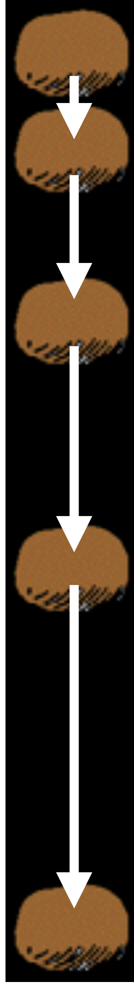
ENERGY TRANSFORMATION

- Stone in free fall:
  - ➡begins at rest — PE_g
  - ➡picks up speed/ loses height — $PE_g + KE$
  - ➡hits the ground (nearly) — KE

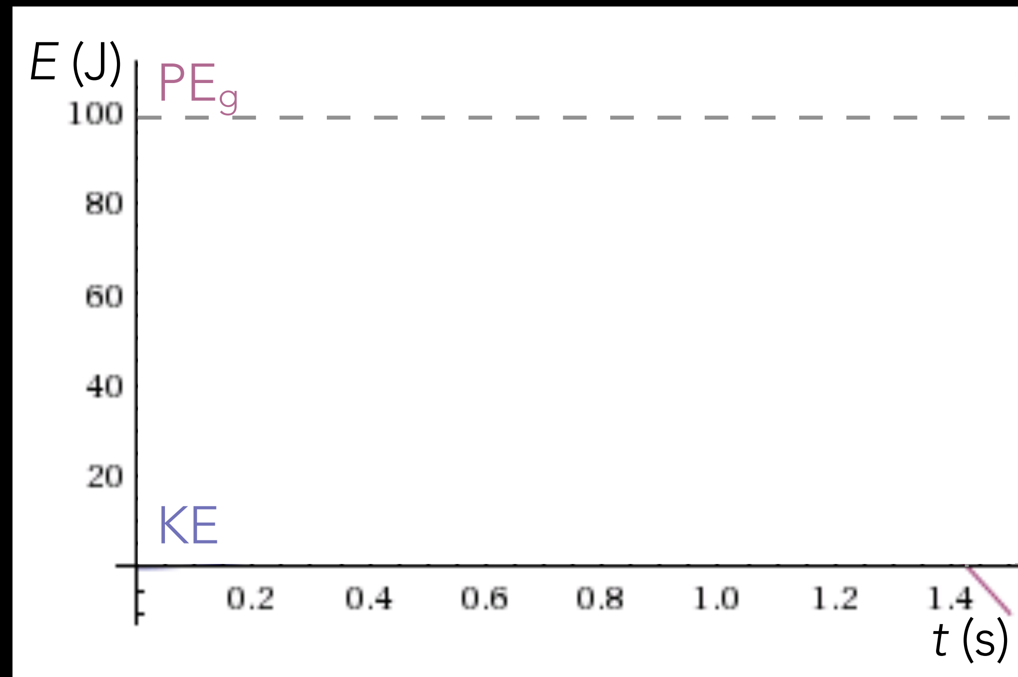
$$PE_g \downarrow PE_g + KE \downarrow KE$$



ENERGY TRANSFORMATION: FREE FALL

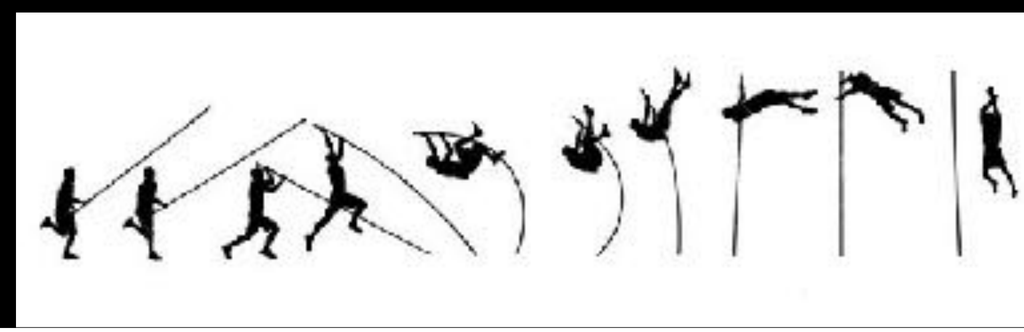


$m = 1$ kg, $h = 10$ m



ENERGY TRANSFORMATION

- Pole vaulter:
  - ➡running
  - ➡flex the pole
  - ➡lift off ground
  - ➡projectile through air
  - ➡land
- Pole vaulter (energy):
  - ➡KE
  - ➡PE_E (+ KE)
  - ➡PE_E + KE (+ PE_g)
  - ➡KE + PE_g
  - ➡Sound & heat



- Work is done by the person on the pole and later by the pole on the person
- Work is done by water on a turbine
- Work is done by a bow on an arrow
- *Work is done when energy is transferred from one object to another*
  - *(or, if the objects are at different temperatures, heat can flow between them instead/in addition)*

LAW OF CONSERVATION OF ENERGY

The total energy is neither increased nor decreased in any process. Energy can be transformed from one form to another, and transferred from one body to another, but the total amount remains constant

PRACTICE V: SKYDIVE

- A 65 kg skydiver drops out of an airplane from an altitude of 4.0 km and opens her parachute after she's fallen 3.0 km
- Using conservation of energy, calculate her speed the moment before she launches the parachute (neglect air resistance)

- Ans. v_f = 240 m/s

POWER

- Average power is the *rate at which work is done*
- or the *rate at which energy is transformed*

$$P = \frac{dW}{dt}$$

power *= the rate at which* ***work*** *is done over* ***time***

POWER IS…

- measured in watts (W)
- 1 watt = 1 joule/sec

POWER

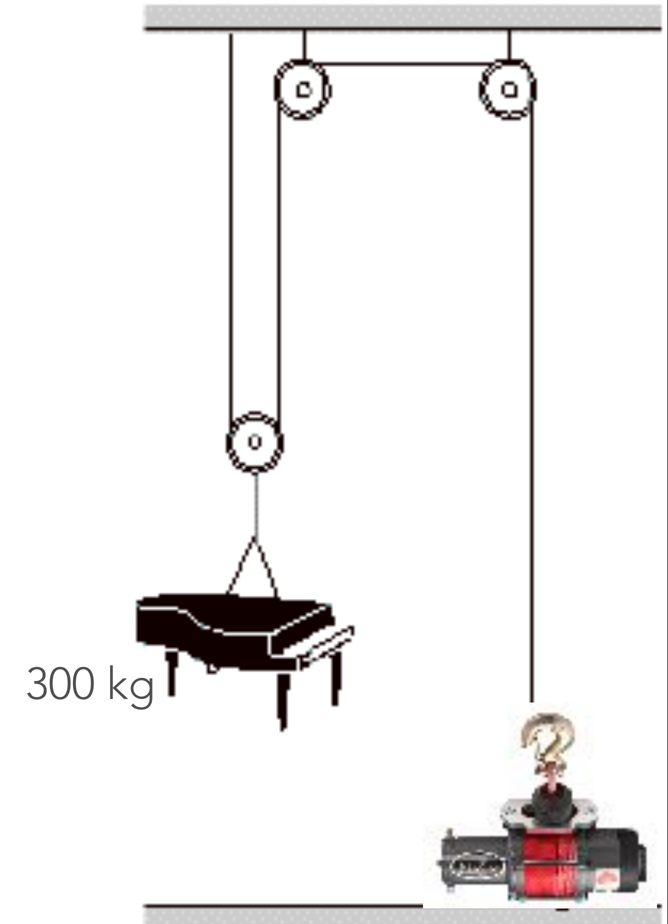
A 40 W lightbulb transforms 40 J of electrical energy into light and heat energy every second

PRACTICE VI: WHICH WINCH IS WHICH?

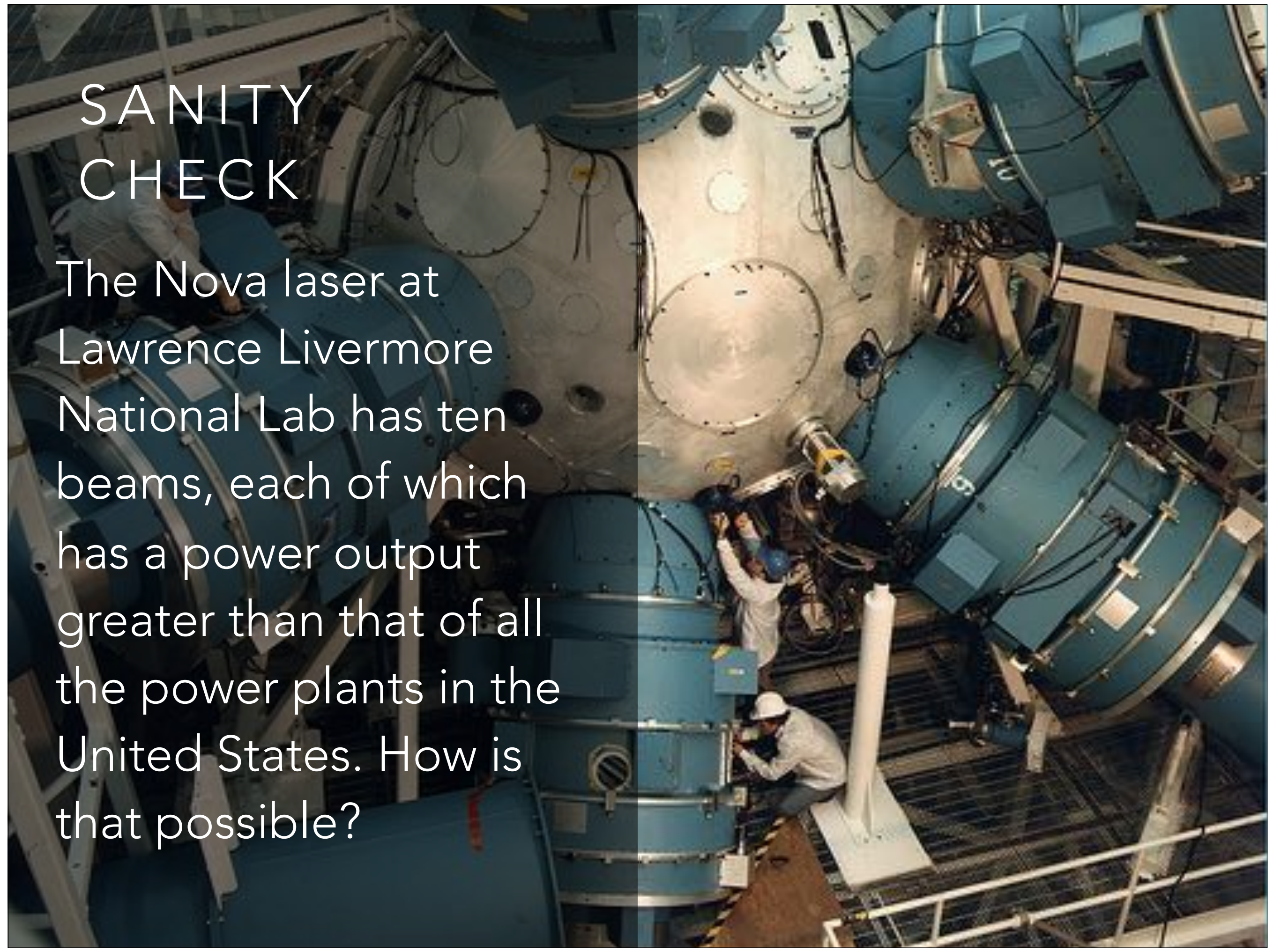
A 300-kg piano needs to be lifted to a sixth-story window 20 m above.

a) What is the minimum amount of work required to lift it?

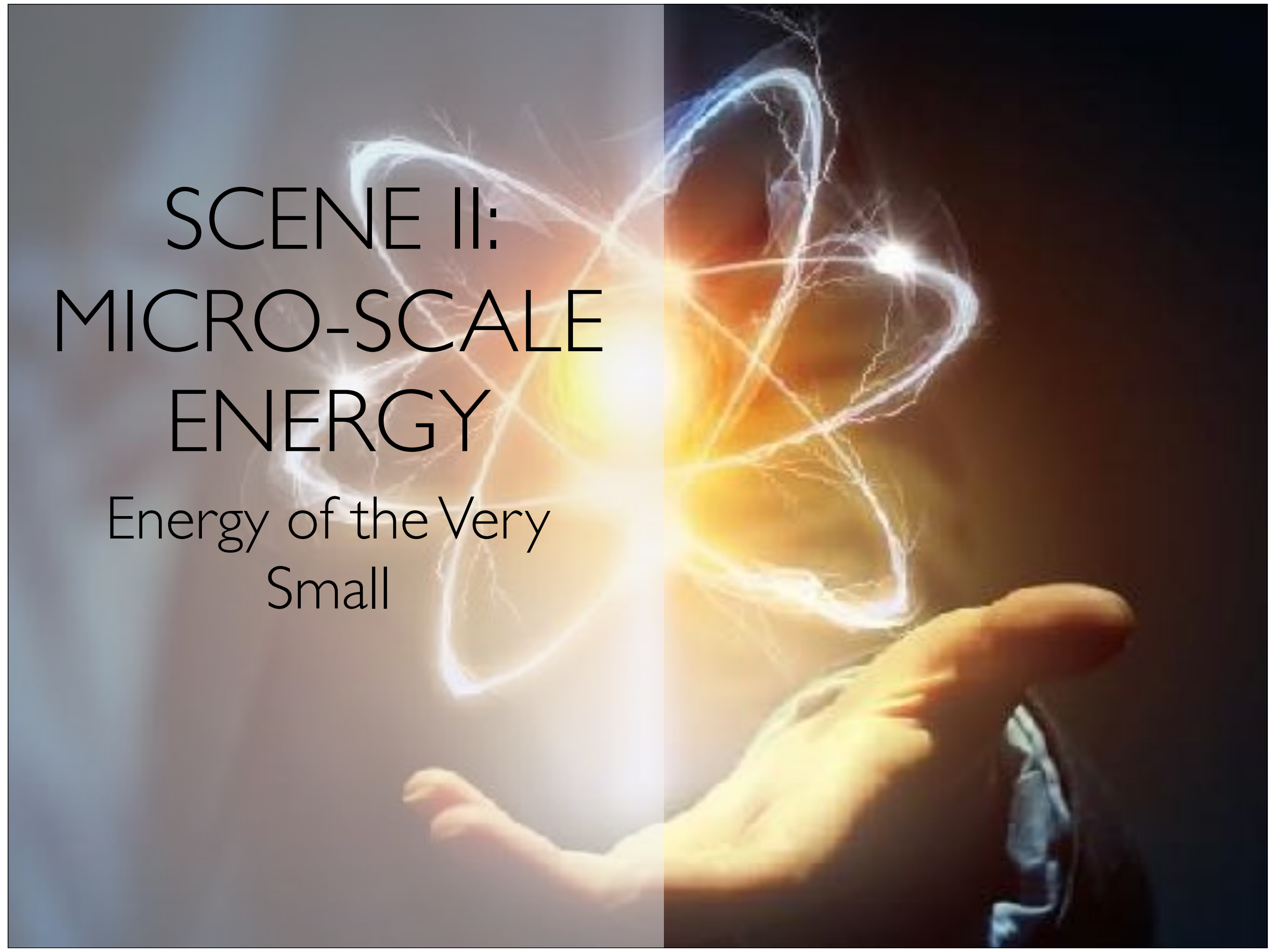
b) If the piano is lifted using a winch powered by a 2000-W motor, what is the minimum amount of time it will take to lift?

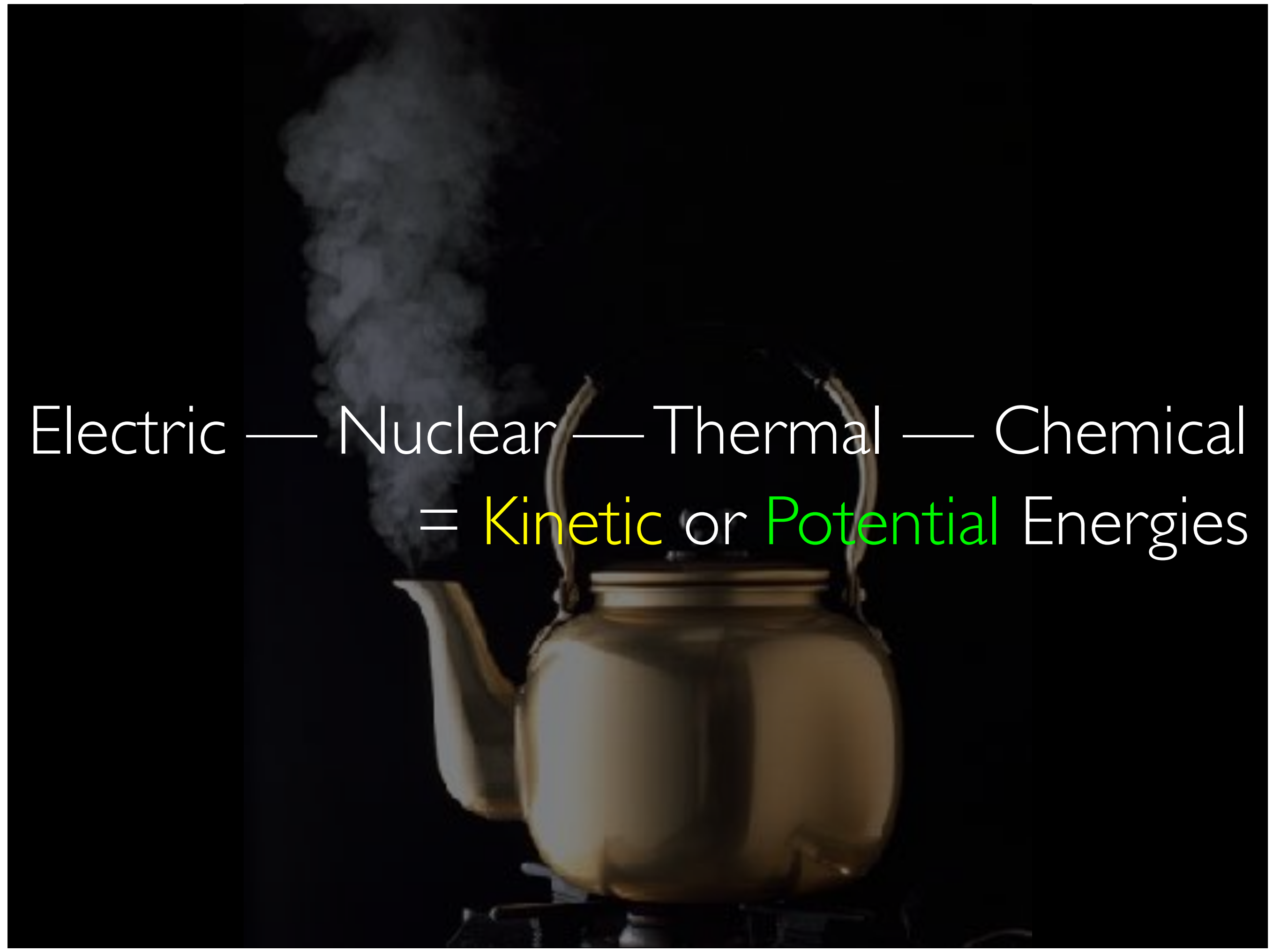


- Answers:
  - a) W = 60,000 J
  - b) t = 30 s



No violation of conservation of energy here. The *energy* the laser uses is much less than the power plants can output, but the laser releases that energy extremely quickly, hence the high power

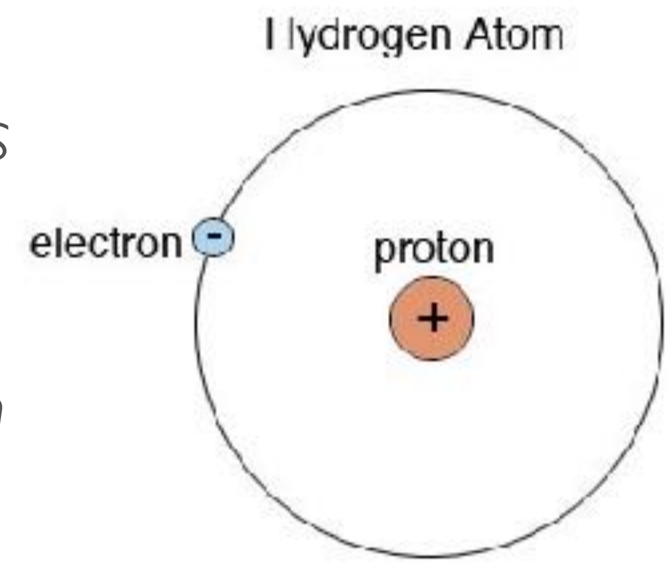

SCENE II:
MICRO-SCALE
ENERGY
Energy of the Very
Small



- E.g. thermal energy is KE of rapidly moving atoms or molecules. When heating an object, the molecules that make it up move around faster
- Energy stored in food or fuel is PE stored by virtue of relative position of atoms within molecule due to electric forces between atoms, i.e. chemical bonds. That potential energy is released through chemical reactions

MASS ENERGY

Fact: *A hydrogen atom has less mass than the combined masses of the proton and electron that make it up*



$$E = mc^2$$

energy *equals* ***mass*** *times* ***the speed of light*** *squared*

- Understanding what this equation means will help us understand how something can weight less than the sum of its parts

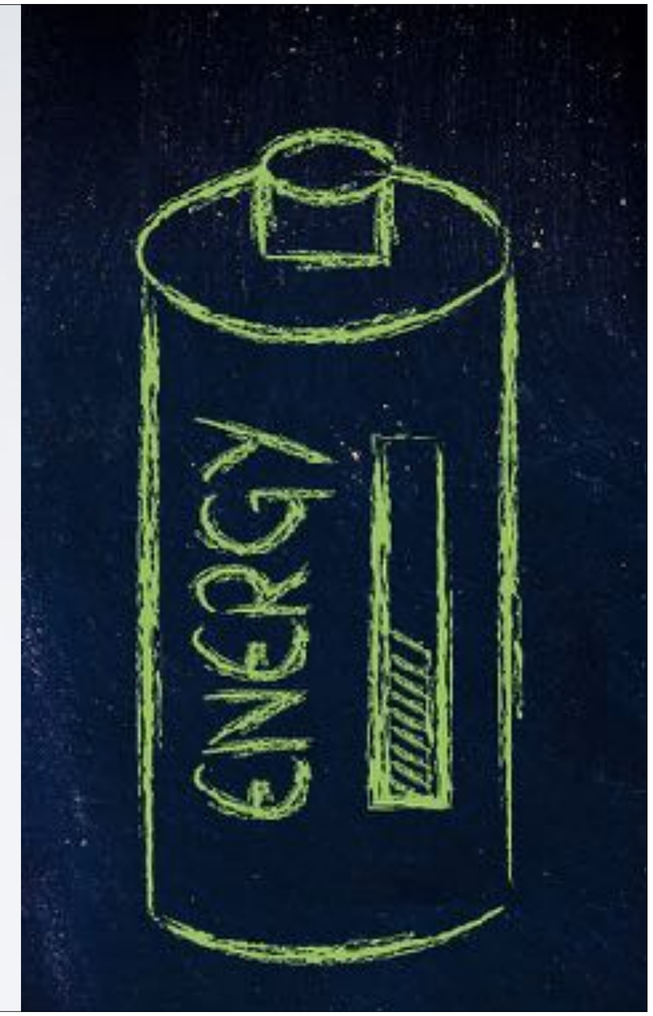
$$E = mc^2$$

energy *equals* ***mass*** *times* ***the speed of light*** *squared*

- Originally, Einstein wrote his famous equation as $m = E/c^2$, because at its heart, this equation is really a lesson in how to think about what mass is

MASS ENERGY

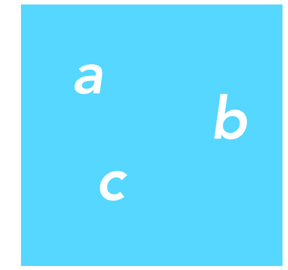
- ~~"Mass is a form of energy"~~
- ~~"Mass is frozen energy"~~
- ~~"Mass can be converted into energy"~~



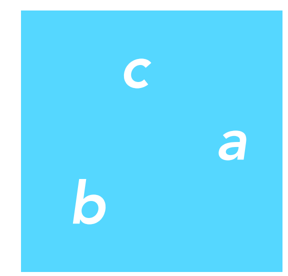
MASS ENERGY

- Two objects made of the same parts will not, in general, have the same mass
- Instead the mass depends on
    1. How those parts are arranged
    2. How those parts move within the bigger object

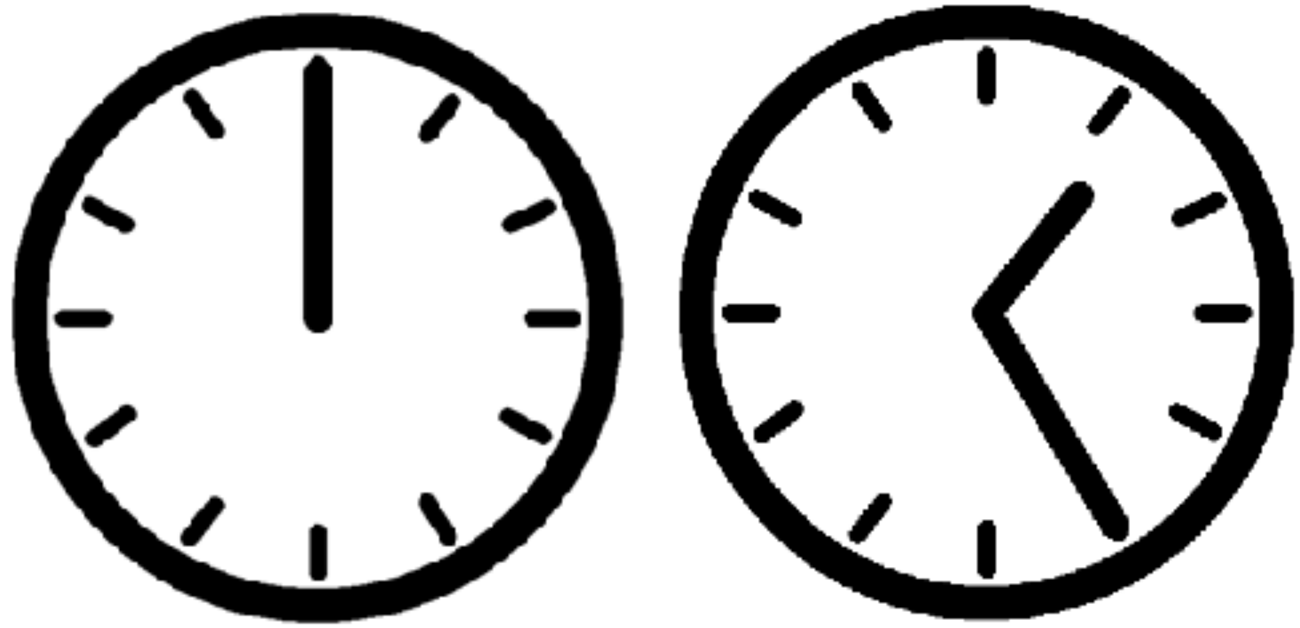
$$m_1 \neq m_a + m_b + m_c$$



$$m_2 \neq m_a + m_b + m_c$$



Fully Wound Up & Running Stopped



$$m > m$$

MASS ENERGY

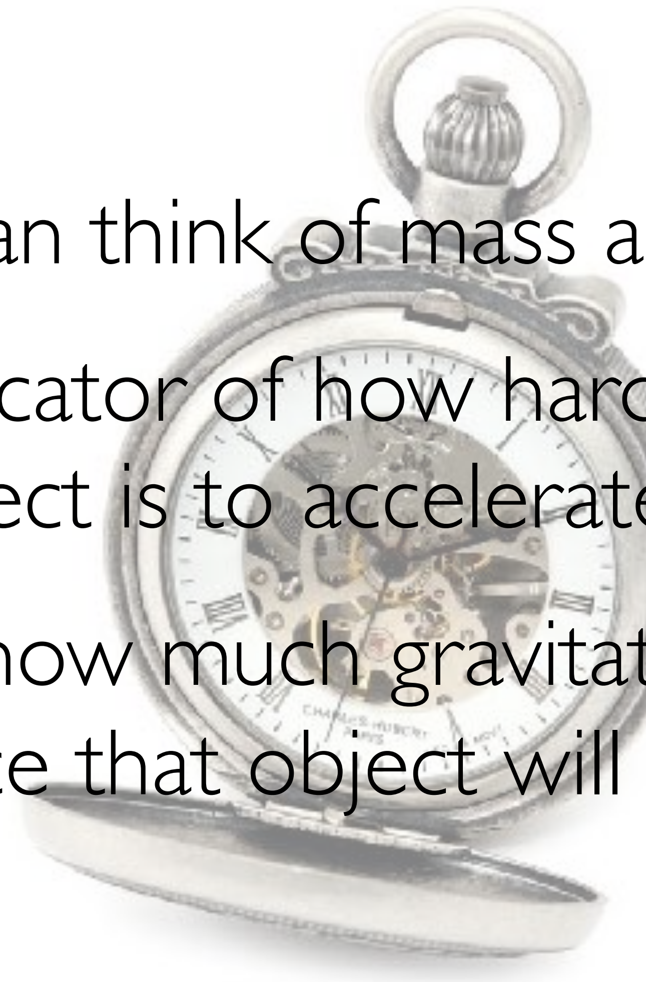
- $m_{\text{watch}} = m_{\text{parts}} + m_{\text{extra}}$

  KE

  PE

  E_{thermal}

  - $m_{\text{extra}} = \dfrac{\text{KE} + \text{PE} + E_{\text{thermal}}}{c^2}$
  - $m_{\text{extra}} \approx 0.00000000000000000001\%\ m_{\text{watch}}$
  - $m \neq$ amount of matter

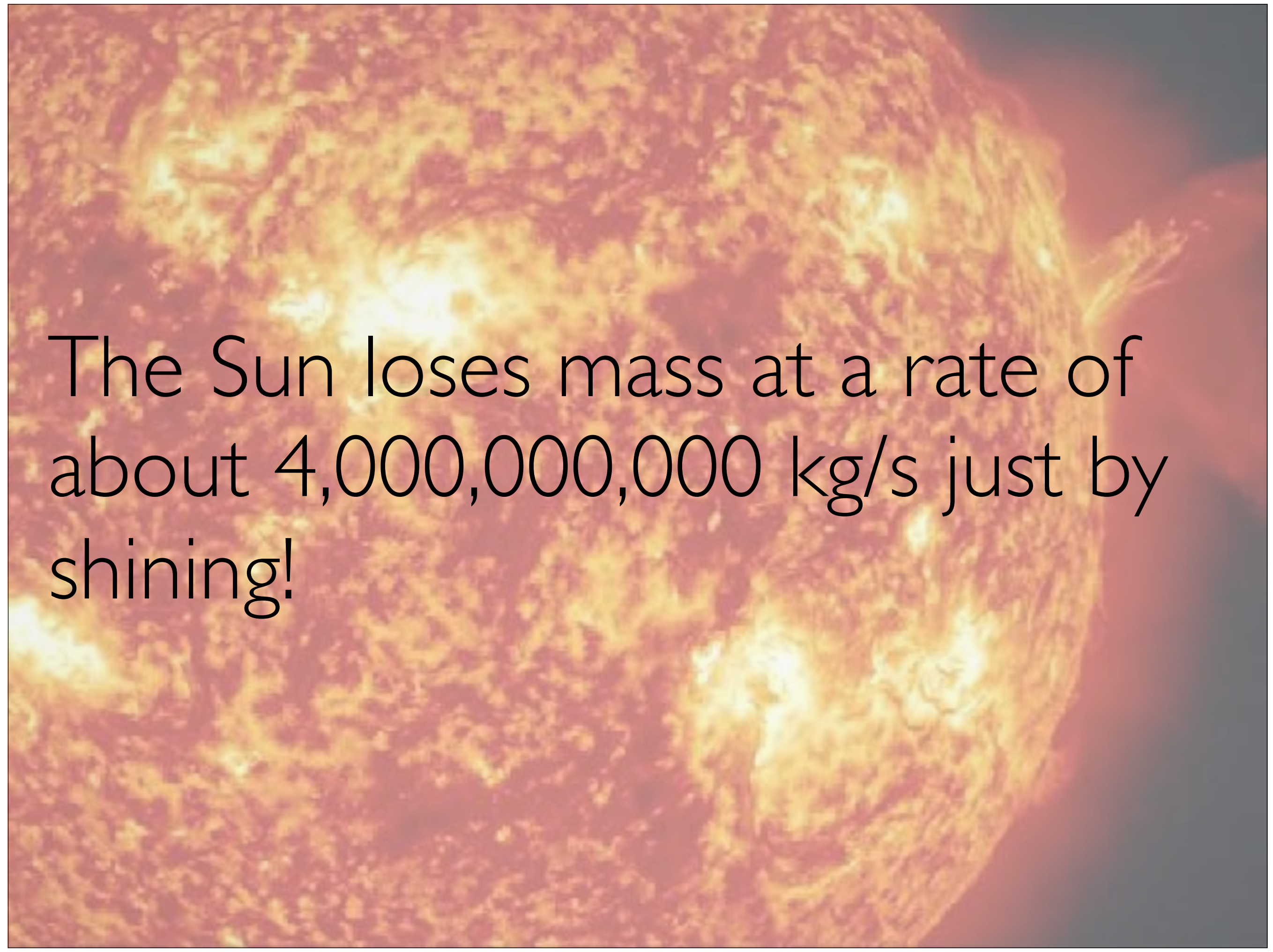


You can think of mass as

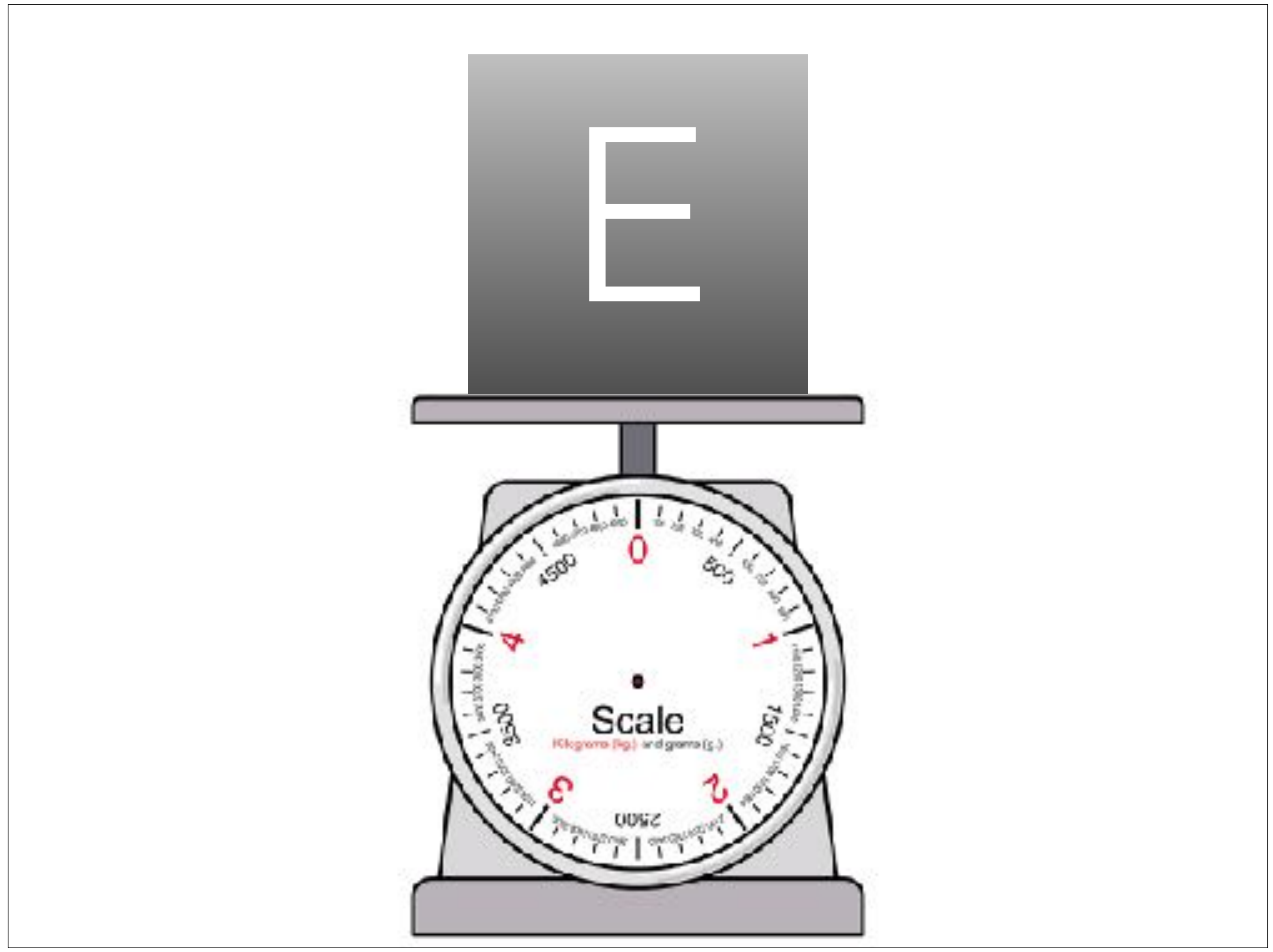
- Indicator of how hard an object is to accelerate
- or how much gravitational force that object will feel

- Either way, a ticking watch has more of it than an otherwise identical stopped watch


Fact: As soon as you turn on a
flashlight, its mass begins to drop



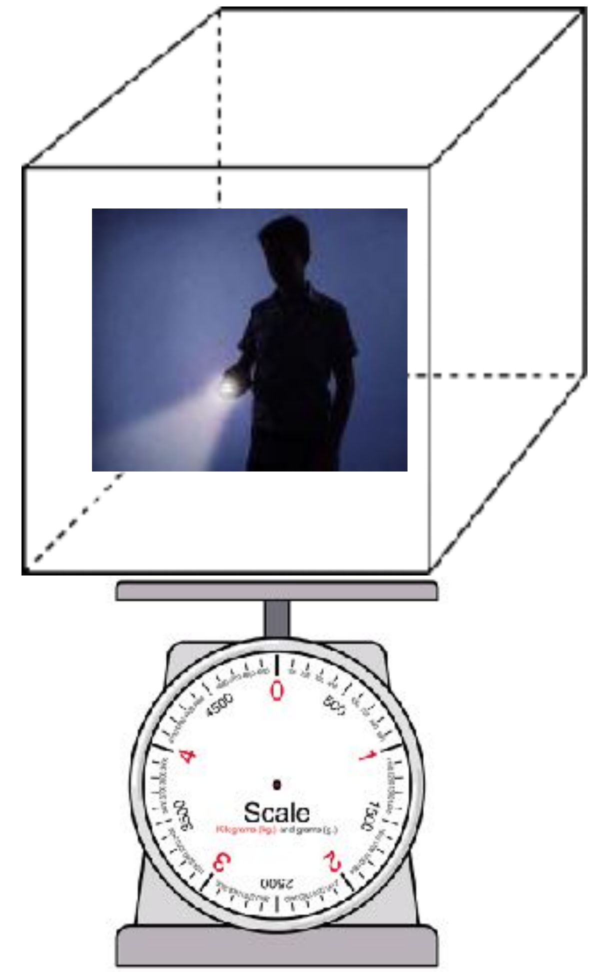
- Does this mean the Sun is converting mass to energy? No!
- $KE + PE \rightarrow E_{light}$



- Any time you weigh something on a scale, you're actually measuring the total energy of that object!

SANITY CHECK

- Suppose that I stand with a flashlight in a closed box that has mirrored walls and is resting on a scale
- Will the reading on the scale change if I turn on the flashlight?



- Answer: Nope! The energy can change forms or move around, but as long as the energy never leaves the box, the mass of the system will remain the same

MASS ENERGY

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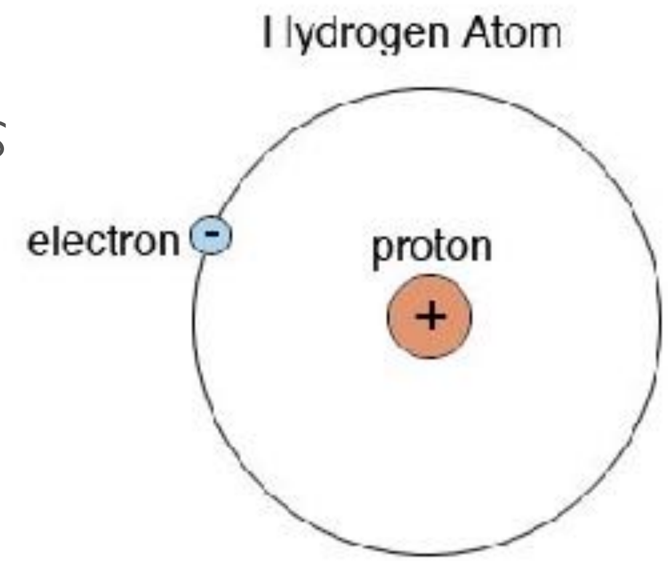
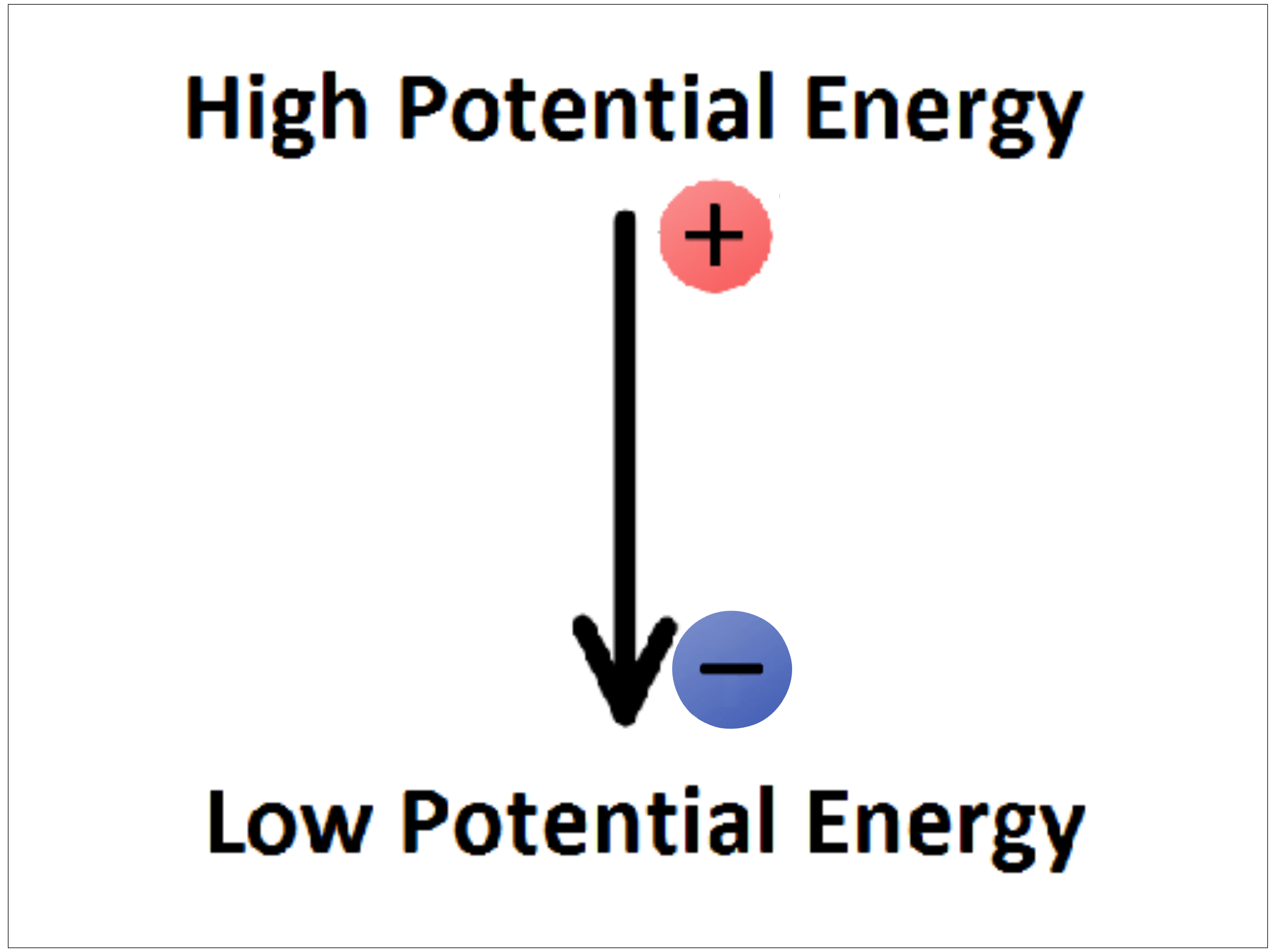


Potential Energy can be *negative*

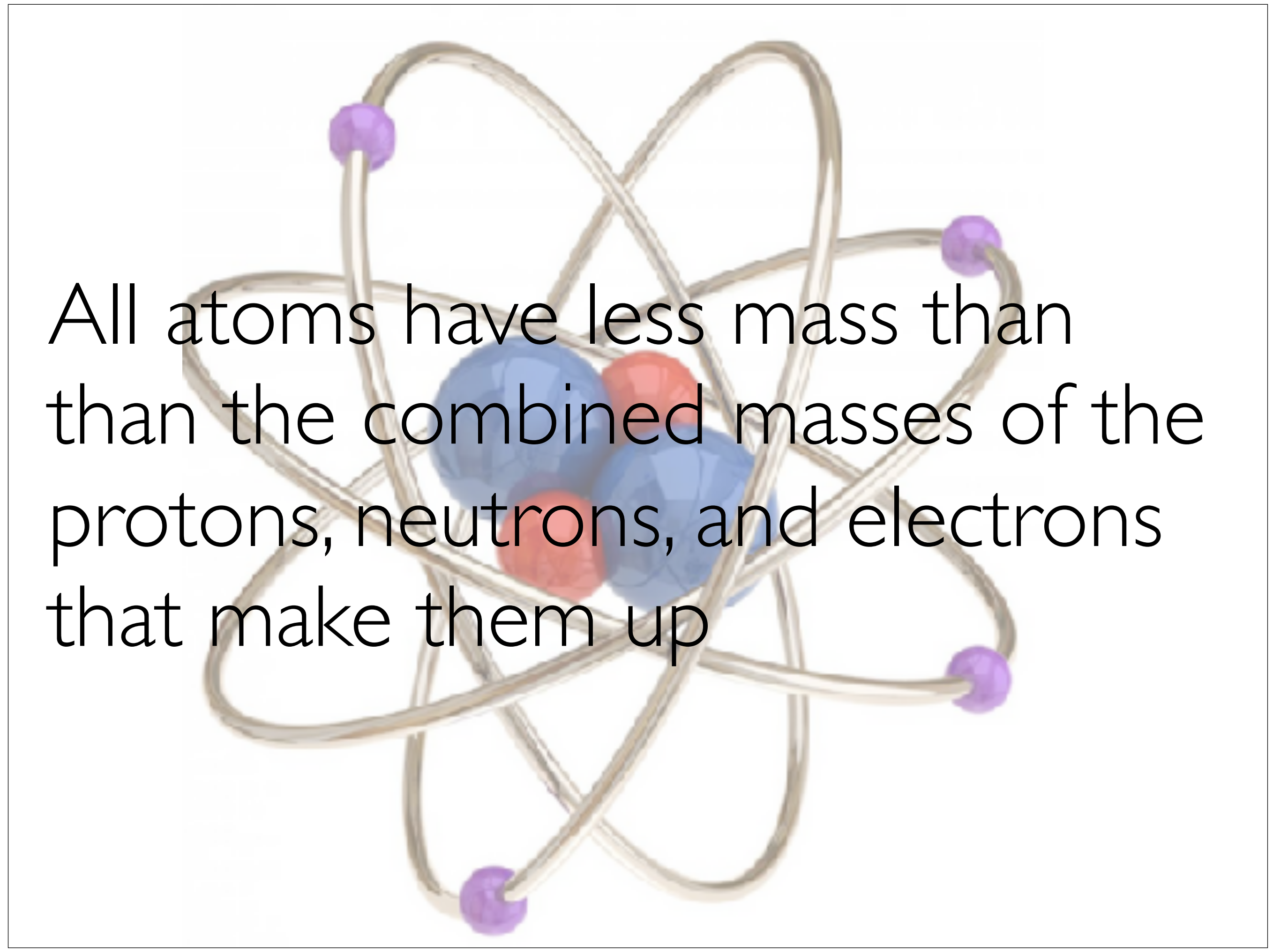
If left to their own devices, all objects move from high potential energy to low potential energy



- When infinitely far away, the electric potential energy between a proton and electron is zero since they can't have any influence on each other
- Bring them just a little closer and they attract each other. As they get closer together their potential energy will drop, going from zero to more and more negative

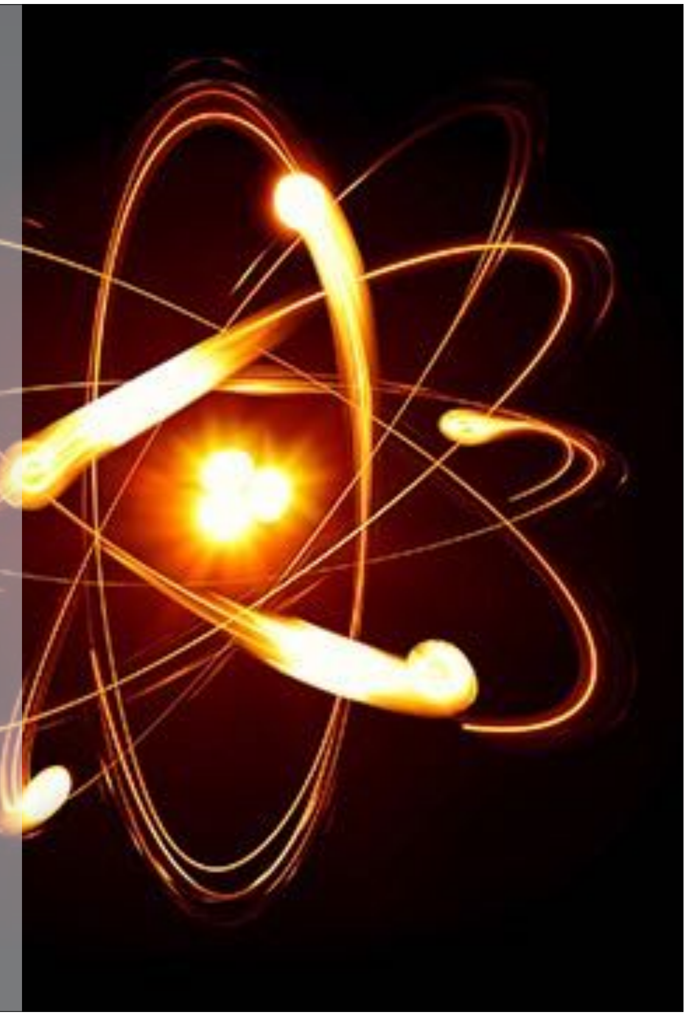
The electron also has kinetic energy (always positive) as it orbits the proton

- Since the electron's potential energy is greater than it's kinetic energy:
  - $KE + PE < 0$
- Because the total energy is negative, it actually takes away from the total mass of the atom
  - $m_{extra} = (KE + PE)/c^2 < 0$



- Same is true for molecules
  - An O_2 oxygen molecule weighs less than two oxygen atoms

- What about the masses of protons and neutrons?
  - They're made of quarks
  - Mass from quark potential energy
- Electrons and quarks aren't made of smaller things
  - Even this mass is a reflection of various kinds of potential energies!
- https://www.youtube.com/watch?v=Ztc6QPNUqls



Moral of the story:

Mass is a ***property*** *— a property that all energy exhibits*

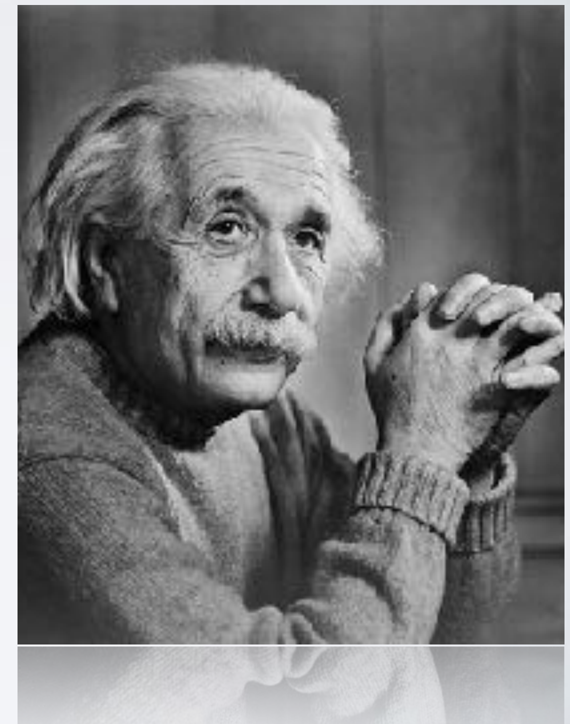
$m \neq$ amount of stuff

$m =$ amount of energy

FURTHER READINGS

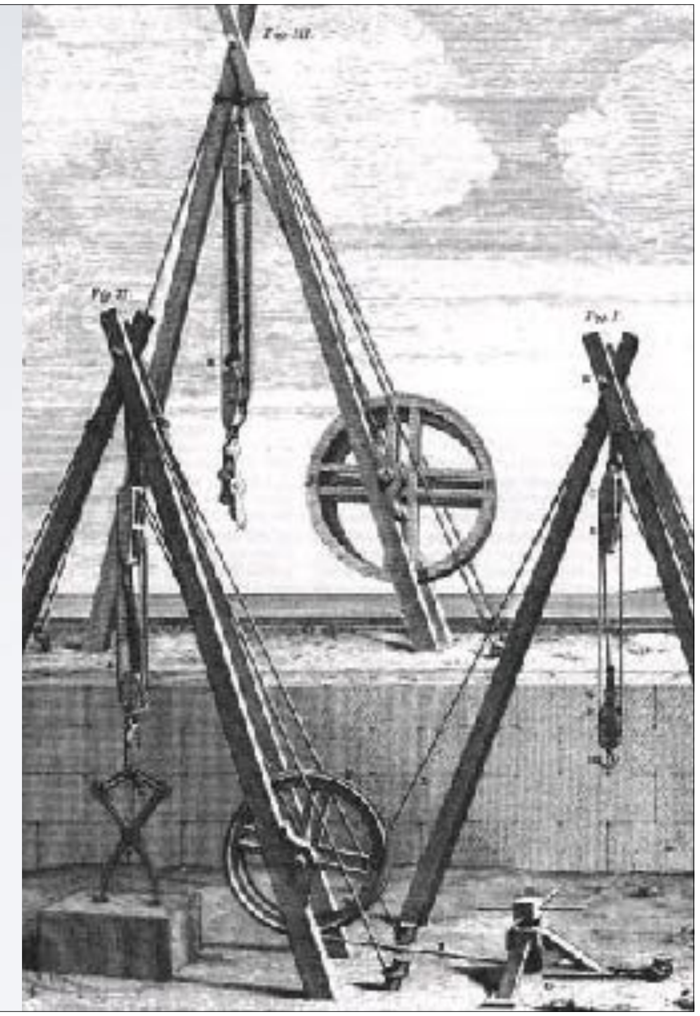
Einstein's original 1905 paper: http://einsteinpapers.press.princeton.edu/vol2-trans/186?ajax

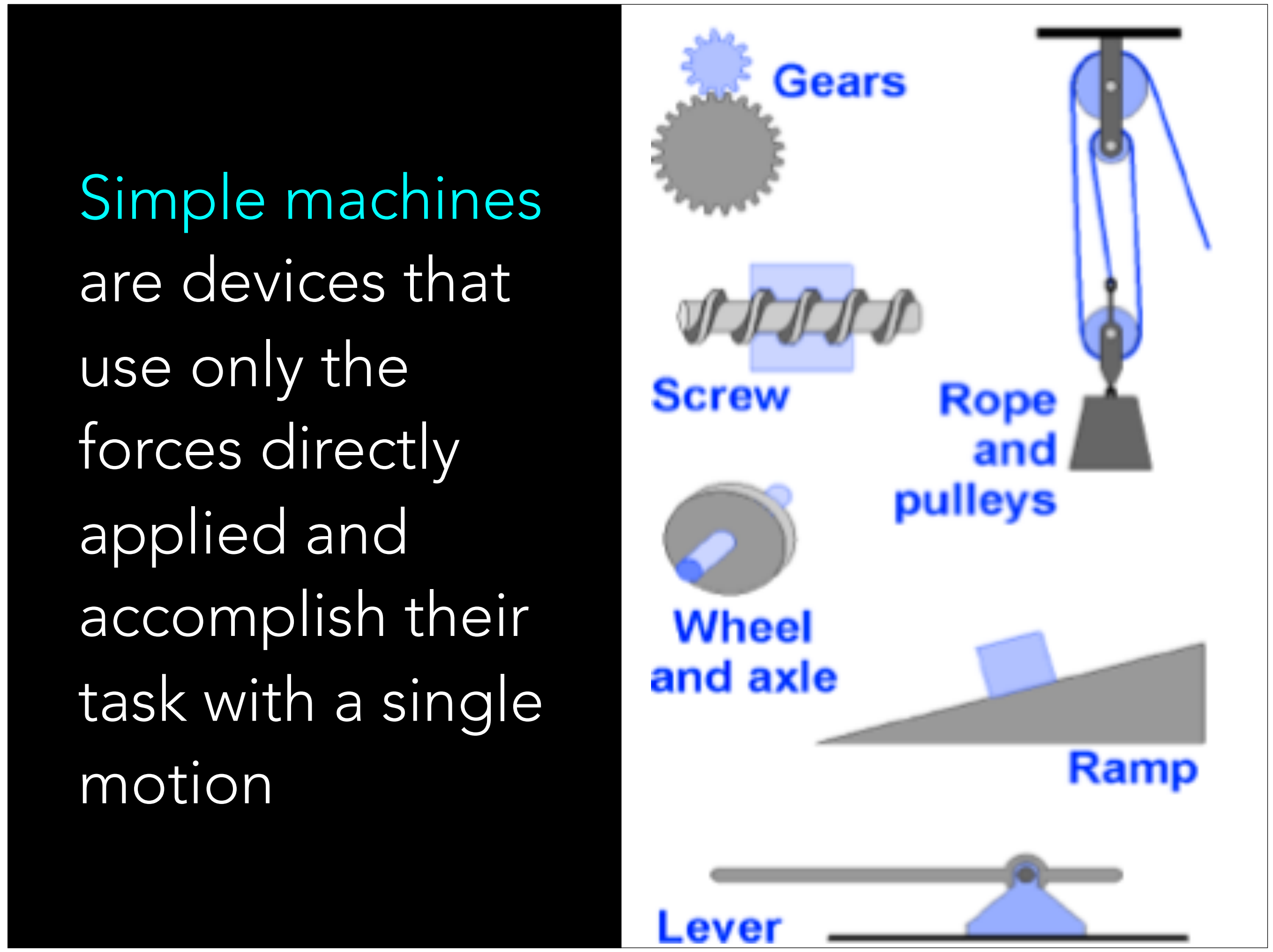
Lorentz Transformation: https://www.youtube.com/watch?v=sbNEtMUjiMU



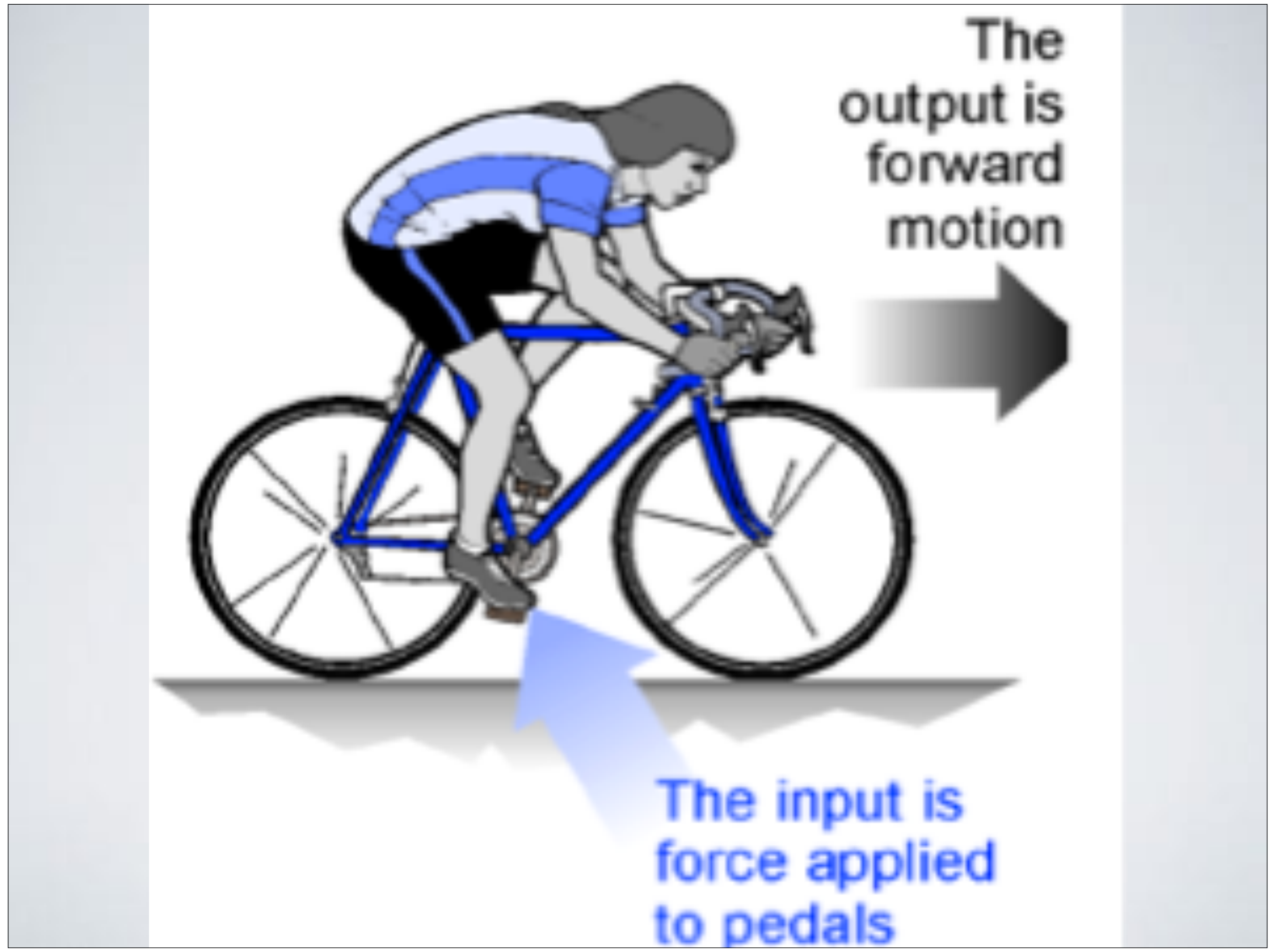
SCENE III: MACHINES

Doing the work you didn't want to do since 2.3 million B.C.





- Machines are designed to take advantage of the relationship between work, force, and distance



- The best way to analyze what a machine does is to think about the machine in terms of input and output
- Still constrained by conservation of energy

INPUT OUTPUT

$$Work_{in} = Work_{out}$$

$$(F\, d)_{in} = (F\, d)_{out}$$

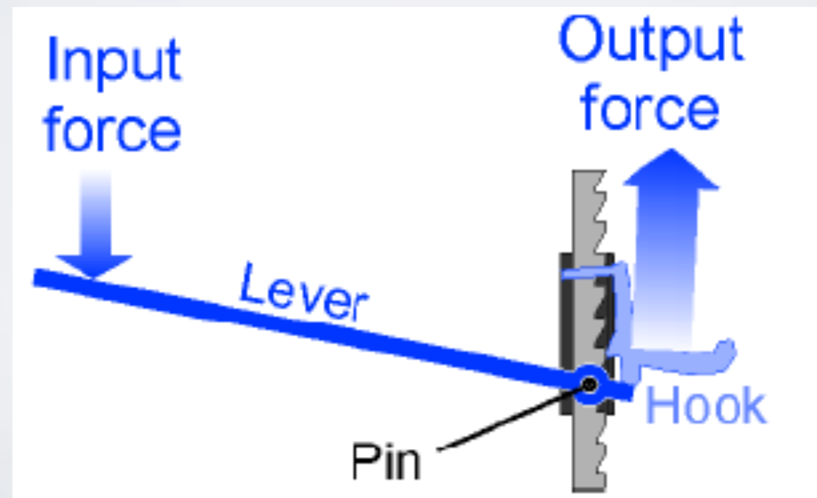
- At the *absolute best*, you get out just as much energy as you put in
- The point of a machine is to take a small force applied over a large distance on the input side and get a large force applied over a small distance on the output side

$$MA = \frac{F_{out}}{F_{in}}$$

mechanical advantage = *the ratio of* ***output force*** *to* ***input force***

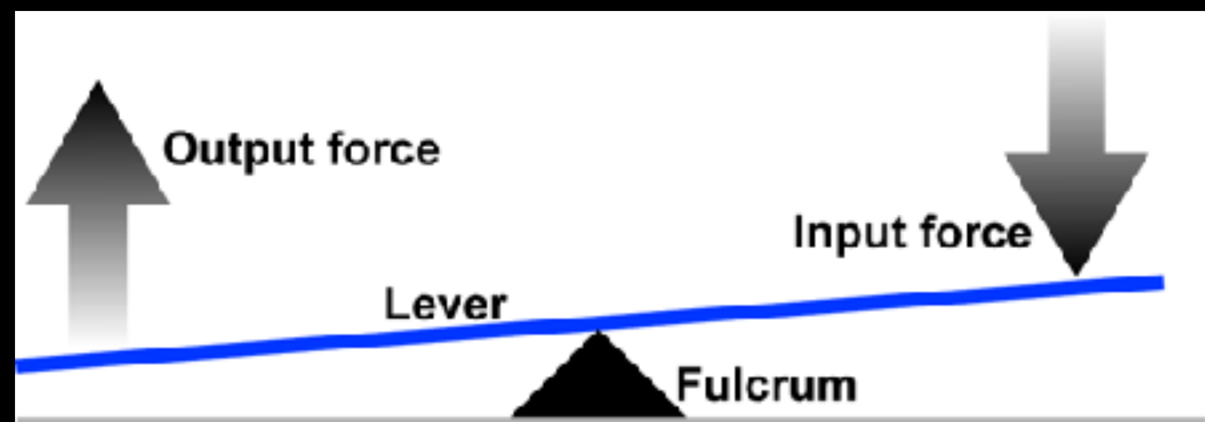
A typical automotive jack has a mechanical advantage of 30 or more

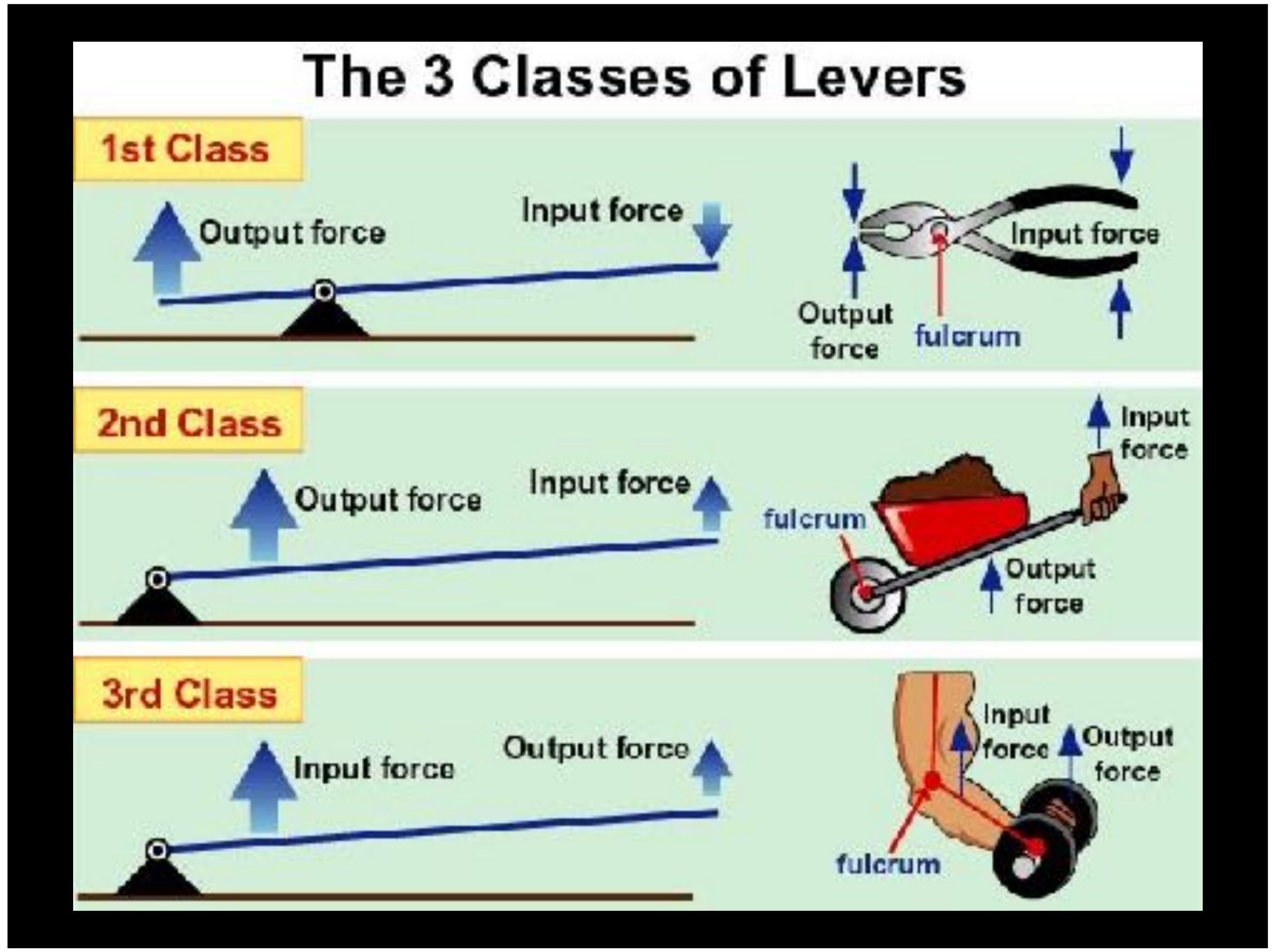
i.e. a force of 100 N (22.5 lbs) applied to the input arm of the jack produces an output force of 3,000 N (675 lbs)— enough to lift one corner of an automobile.



LEVER

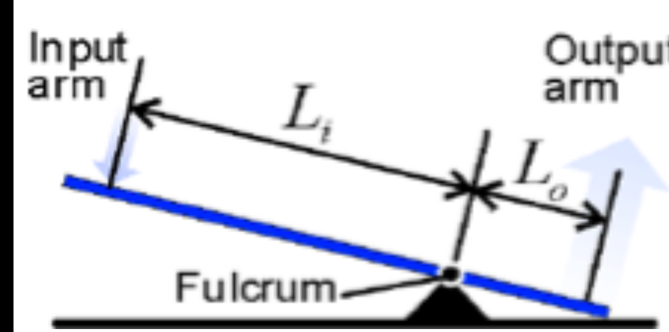
A lever includes a stiff structure (the lever) that rotates around a fixed point called the fulcrum




The 3 Classes of Levers
1st Class
Output force
Input force
Input force
Output force
fulcrum
2nd Class
Output force
Input force
Input force
fulcrum
Output force
3rd Class
Input force
Output force
Input force
Output force
fulcrum

MECHANICAL ADVANTAGE: LEVER

- $MA_{lever} = L_{in}/L_{out}$
- What force must be applied to the end of a 2.0 m long crowbar in order to lift a 500 N rock if the fulcrum of the bar is 0.5 m from the rock?

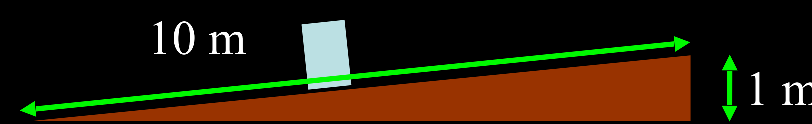


- Ans. F_{in} = 167 N

RAMP

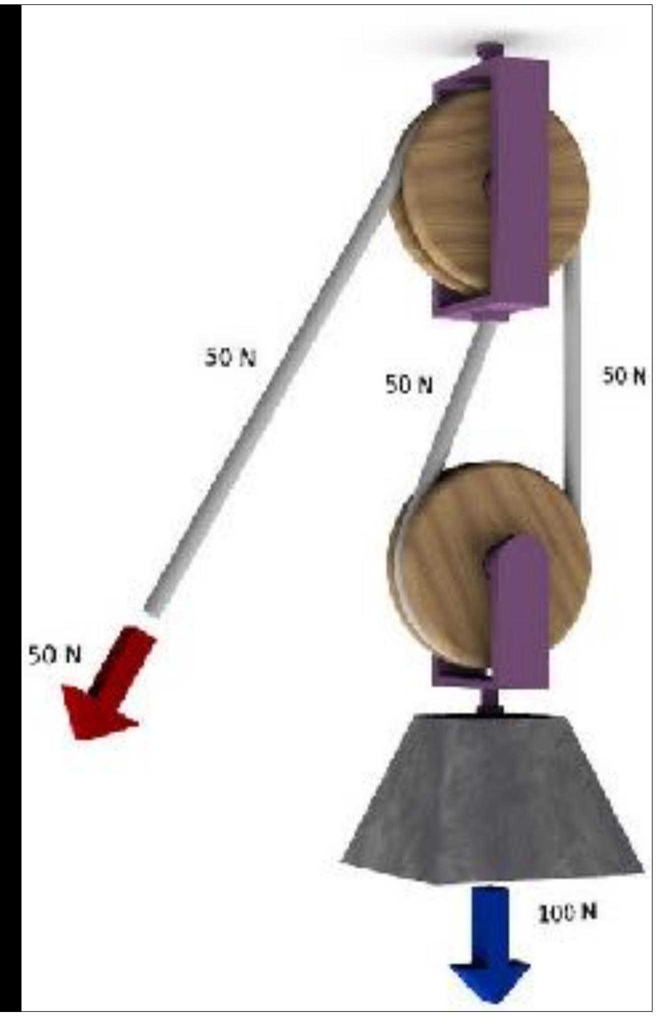
- You need to get a 100 kg couch into a moving van 1.0 m above the ground
- How much work would you need to do to lift it in? How much force would you need to apply?
  - *Ans.* $W = 981\ J;\ F_A = 981\ N$
- Instead you use a ramp 10 m long and 1 m high
- How much work would you need to do to lift it in? How much force would you need to apply?
  - *Ans.* $W = 981\ J;\ F_A = 98.1\ N$

(excludes frictional losses)

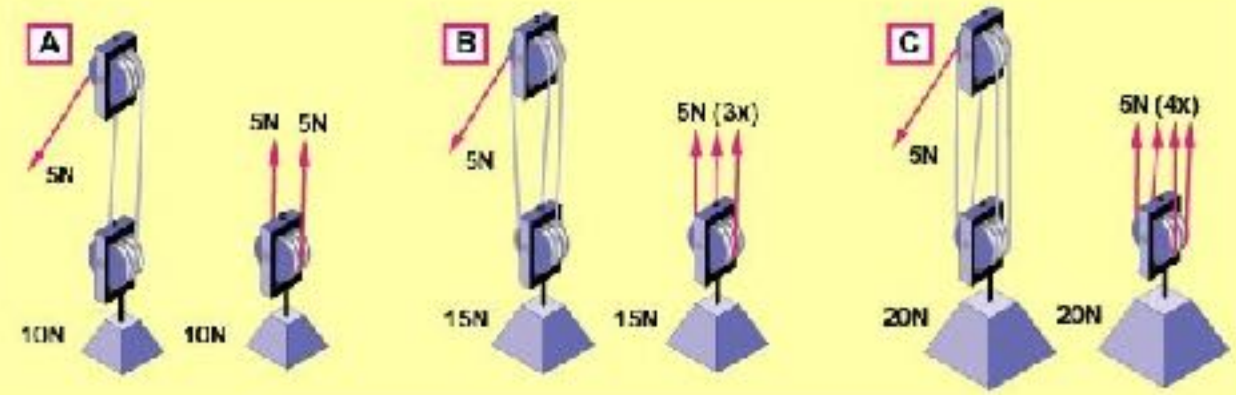


PULLEYS

- Like levers and ramps, pulleys sacrifice displacement to achieve greater force
- MA is shown by how many ropes are supporting the load in this case there are two



Mechanical Advantage



$$\text{Mechanical advantage} = \frac{\text{Output force}}{\text{Input force}}$$

	A	B	C
Input force	5N	5N	5N
Output force	10N	15N	20N
Mechanical advantage	2	3	4

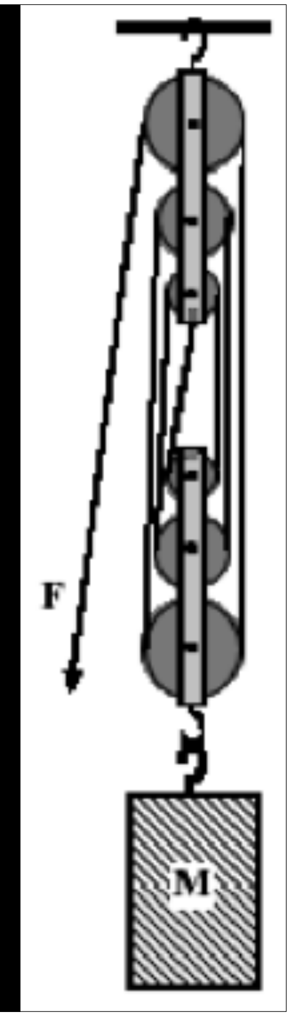
PRACTICE VII: PULLEY PROBLEMS

- A pulley system consisting of six pulleys as shown to the right has an input force of 220 N applied to it. As a result of this input force the mass *M* is lifted a distance of 25.0 cm.

a. What is the force on the output end (what is the weight of the block)?

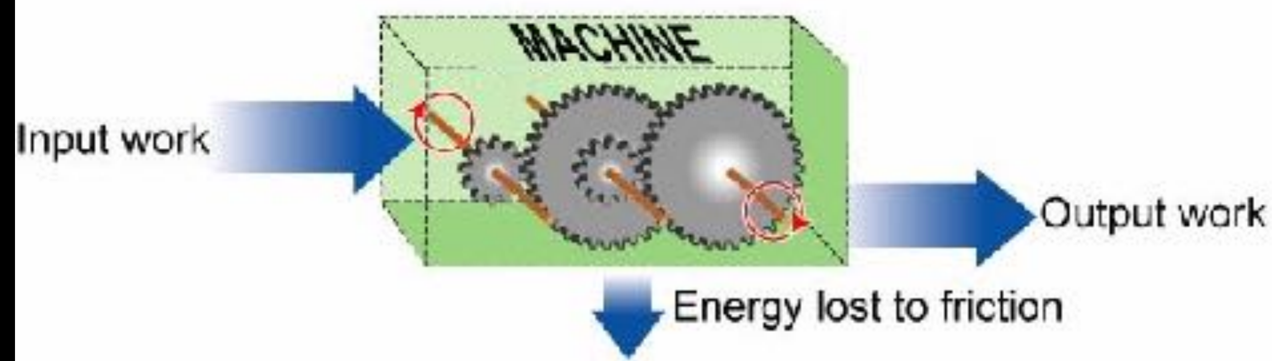
b. Through what distance was the input force applied (how much rope is pulled out)?

c. How much work was done on the mass *M*?



a. F_{out} = 1320 N
b. d_{in} = 1.5 m
c. W = 330 J

Efficiency

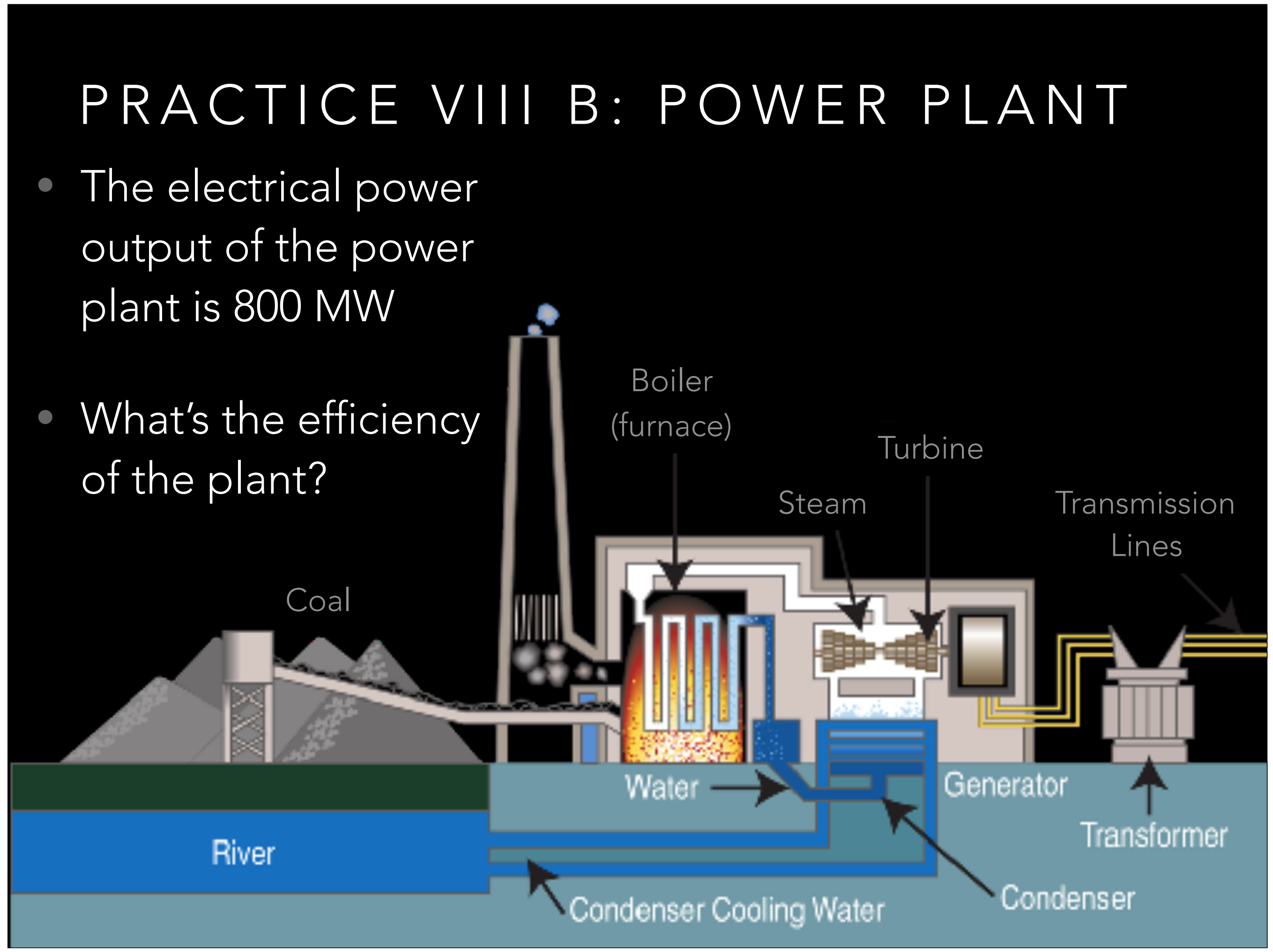


$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}}$$

PRACTICE VIII: POWER PLANT

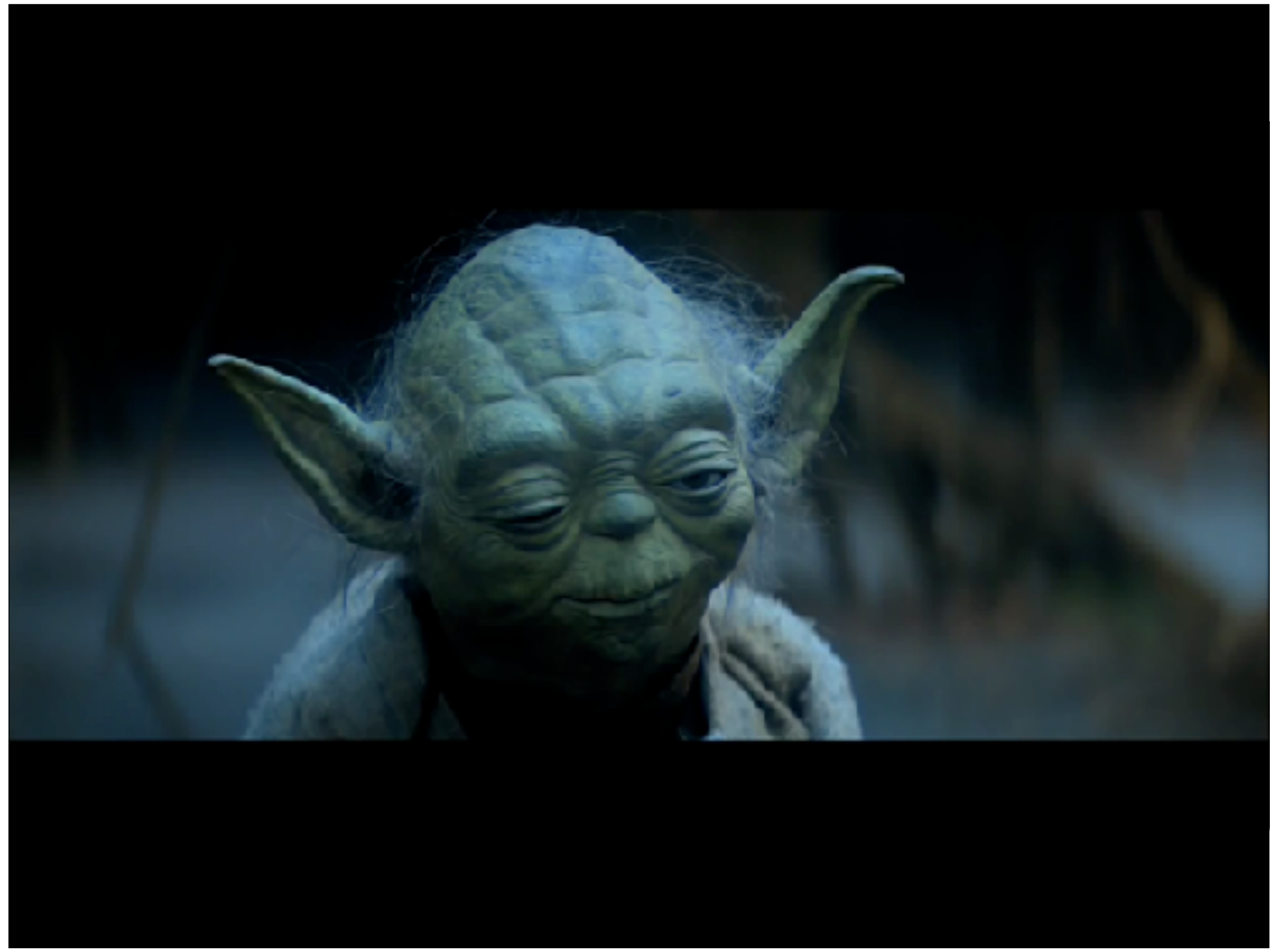
- A power plant burns 75 kg of coal every second. Each kg of coal contains 27 MJ of chemical energy.
- What is the power of the power station, in watts?

- Ans. P = 2.03 GW



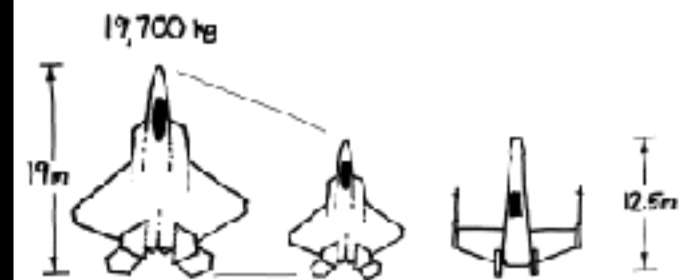
- Ans. *eff.* = 39%
- What happened to the rest of the energy?
    - Wasted as heat - up the chimney of the power station, in the cooling towers, and because of friction in the machinery

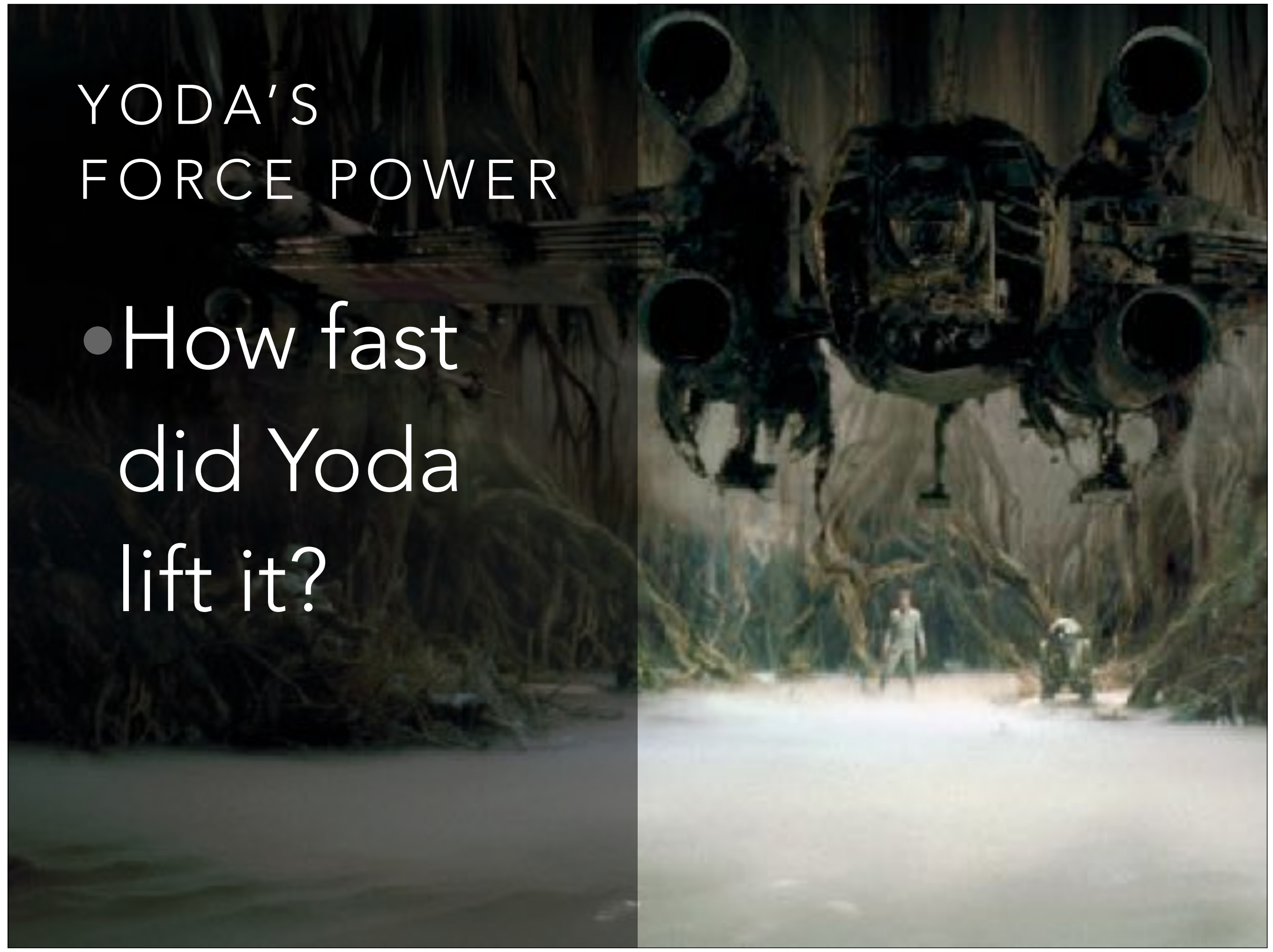
How much Force power can Yoda output?



YODA'S FORCE POWER

- Mass of an X-wing ?
  - *Length* = 12.5 m
  - An F-22 is 19 m long and has a mass of 19,700 kg
  - $m_x = m_{f22} \times (12.5\text{ m}/19\text{ m})^3 \approx 5{,}600$ kg (or ~12,000 lbs)




YODA'S
FORCE POWER
How fast did Yoda lift it?

YODA'S FORCE POWER

- How fast did Yoda lift it?
  - Front strut rises out of the water in about 3 ½ secs.
  - Strut about 1.4 meters long
  - v = 0.39 m/s

YODA'S
FORCE POWER

Strength of gravity on Degobah?

"Yup, that's it. Dagobah. […] No, I'm not gonna change my mind about this. I'm not picking up any cities or technology. Massive life-form readings, though. There's something alive down there."
—Luke Skywalker[src]

Dagobah	
Astrographical information	
Region(s)	Outer Rim Territories[1]
Sector	Sluis sector[1]
System	Dagobah system[3]
Suns	1: Dario[4]
Orbital position	2[4]
Moons	1[4]
Grid coordinates	M-19[4]
Distance from Core	50,250 light years[4]
Rotation period	23 standard hours[2]
Orbital period	341 local days[2]
Physical information	
Class	Terrestrial[2]
Diameter	8,900 km[2]

Dagobah (pronunciation (help·info)) was an Outer Rim planet in the Dagobah system. A remote world of swamps and forests, it served as a refuge for Jedi Grand Master Yoda during his exile after the events of Order 66 had taken place, but otherwise had no notable intelligent life.

Contents [show]

Geography ✎Edit

"Yes, I'm sure it's perfectly safe for droids."
—Luke Skywalker to R2-D2[src]

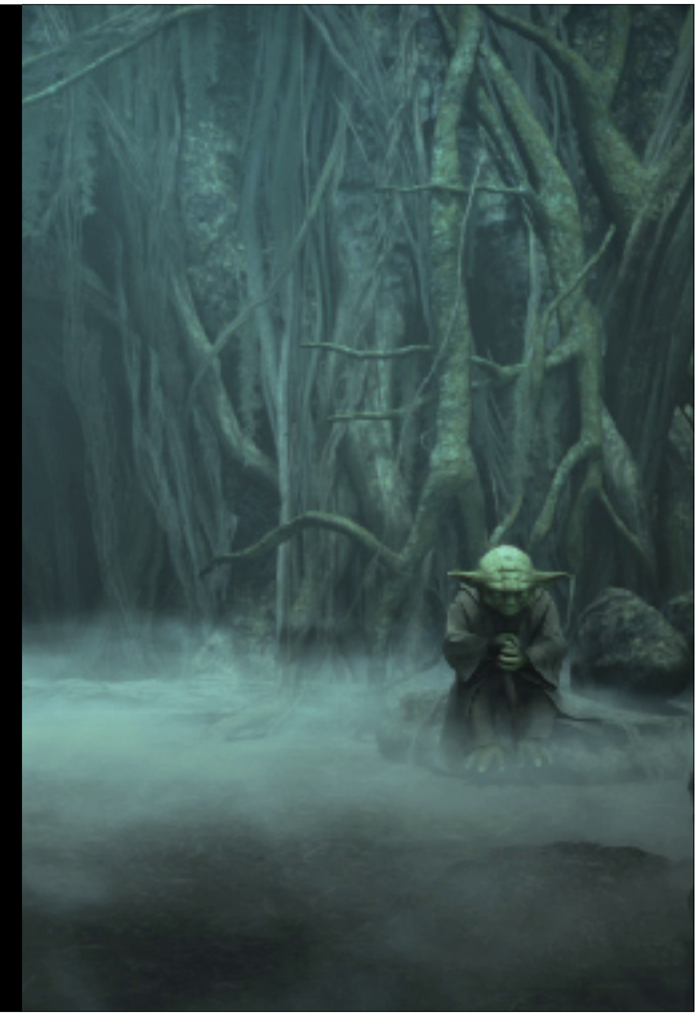
Dagobah was located in the Sluis sector of the Outer Rim Territories. Despite the fact that it was located near the Rimma Trade Route, it was reachable only by obscure hyperlanes.[3]

The swamp-covered surface of Dagobah

Dagobah was a harsh, humid, swampy planet, mostly covered in shallow marshland, interspersed with stifling forests and at least one cave. There were very few truly open bodies of water on the planet; the water supply was thinly

YODA'S FORCE POWER

- Strength of gravity on Degobah?
  - $g_d = 0.9g = 8.83\ \text{m/s}^2$

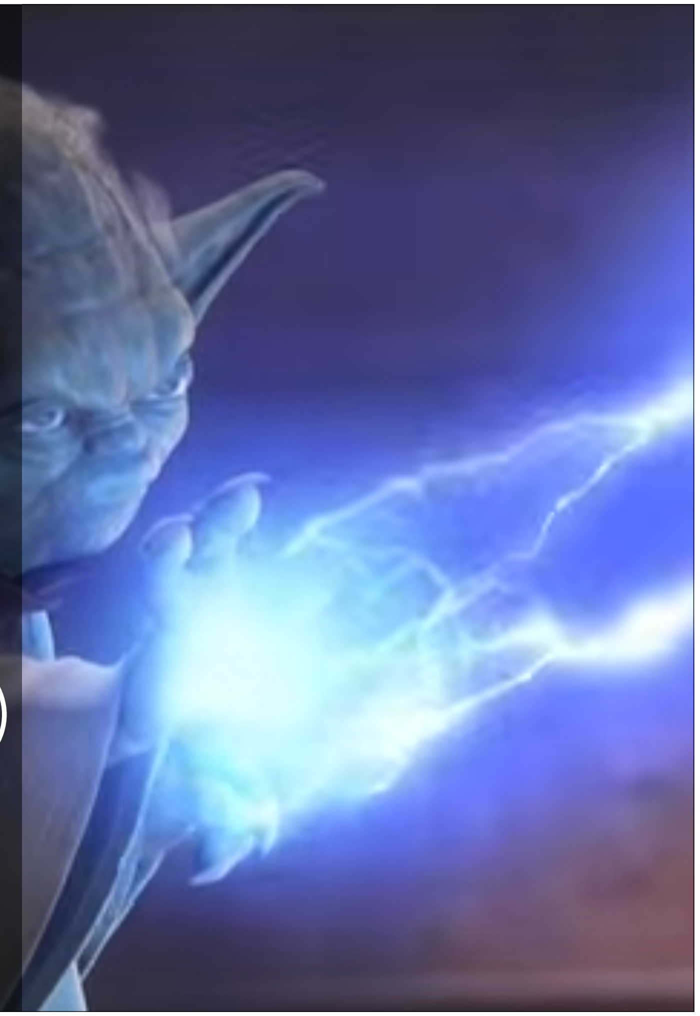


YODA'S FORCE POWER

$P = W/t = Fd/t = mgd/t$

$P = (5600\ \text{kg})(8.83\ \text{m/s}^2)(1.4\ \text{m})/(3.5\ \text{s})$

$\boxed{P = 19.8\ \text{kW}}$



YODA'S FORCE POWER

- Enough to power a block of suburban houses
- ~25 horsepower (about the same as the motor in the electric-model Smart Car)
- At current electricity prices, Yoda would be worth about $2/hour
- With world electricity consumption pushing 2 terawatts, it would take a hundred million Yodas to meet our demands