"ENERGY AND PERSISTENCE CONQUER ALL THINGS" — BENJAMIN FRANKLIN

ENERGY

WHAT IS ENERGY?

- 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

IMPORTANT FACTS

- Energy is a scalar quantity
- Energy is conserved
    - Cannot be created or destroyed, just shuffled around
- The unit for energy is 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

WORK

- $W = F_{||}d$
  - $F_{||}$ because only the part of force that acts parallel to the displacement does work
- $W = Fd\cos\theta$
- Ex. You apply 50 N of force horizontally to move a grocery cart 30 m
  - W = 50 N • 30 m = 1500 J
- Assume the force is *constant*

WORK

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

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

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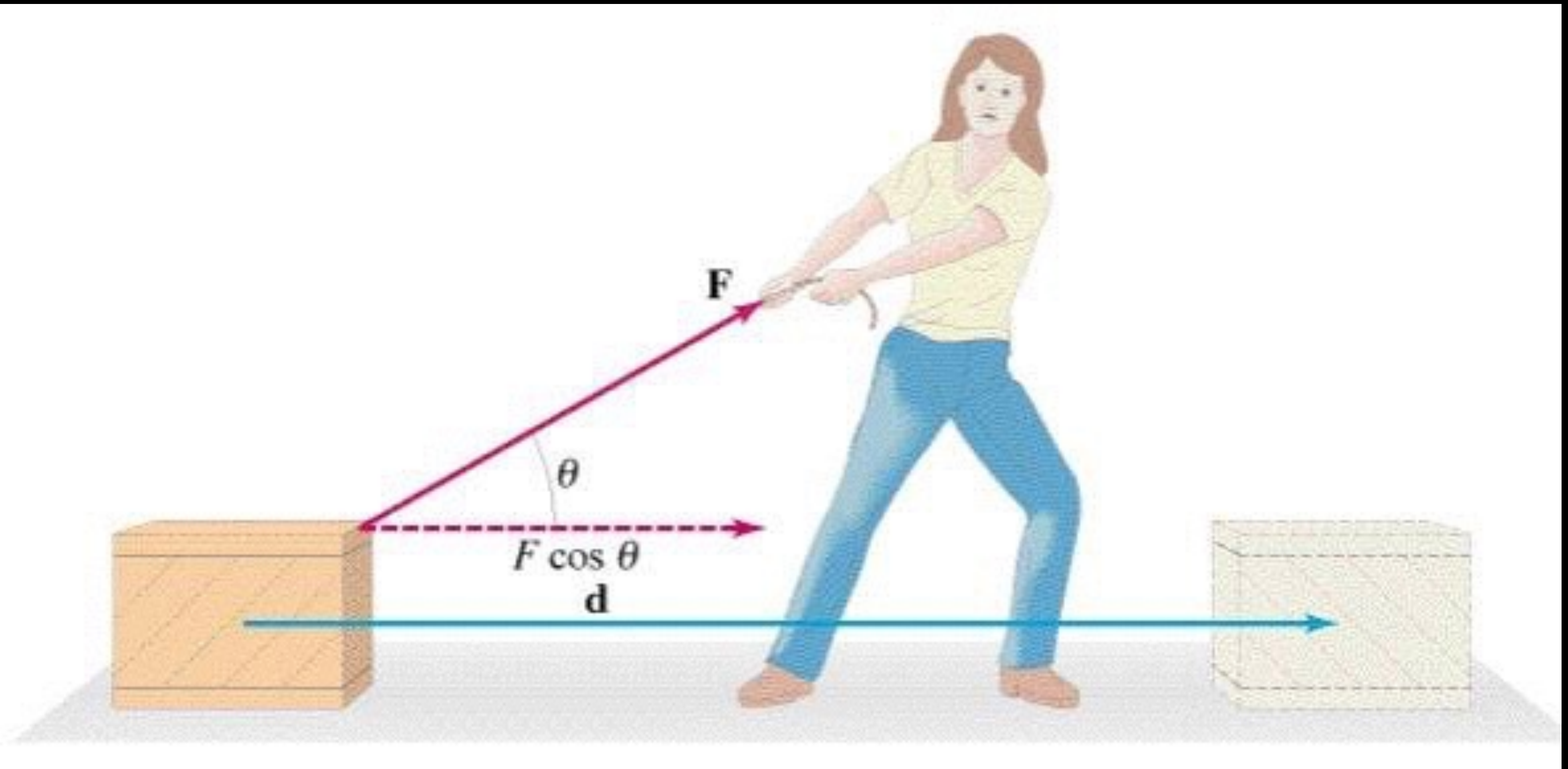
MORE IMPORTANT NOTES

- Work done *by* an object or work done *on* an object?
- Work done by a *particular force* or work done by the *net force*?
- Be specific!

EXAMPLE 1

- You demanded your job pay you in nickels, and now you have 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, at an angle of 37°. The floor is rough and exerts a friction force f = 50 N.
- Determine the work done by each force acting on the crate and the net work done on the crate
  - *Ans.* $W_g = 0$
  - $W_N = 0$
  - $W_A = 3200$ J
  - $W_{fr} = -2000$ J
  - $W_{net} = 1200$ J



NEGATIVE ENERGY

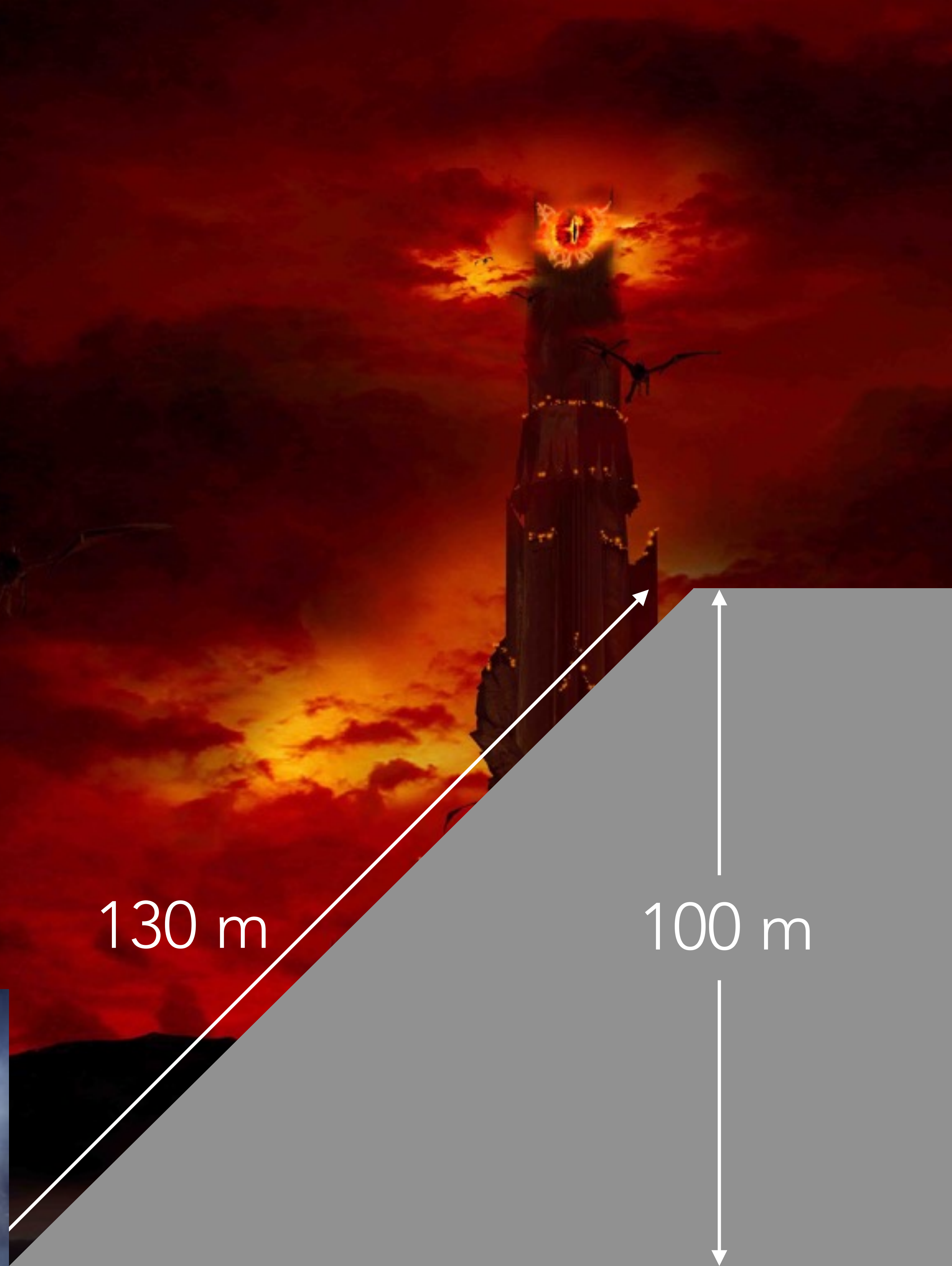
- Notice friction did negative work
- In general, forces done *against* motion do negative work
- More generally, energy put into the system is positive, energy taken out of the system is negative

EXAMPLE 2

- "I can't carry it for you, but I can carry you!" Sam exclaims, hoisting a collapsed Frodo over his shoulders.

- How much work must Sam do on his 50 kg companion to carry him up the 100-m-tall slope of Mt. Doom, clambering over 130 m?

- *Ans.* $W_A = 49\ kJ$



EXAMPLE 2B

- How much work is done by gravity on Frodo?
- *Ans.* $W_g = -49\ kJ$

EXAMPLE 2C

- What is the net work done on Frodo?
- *Ans.* $W_{net} = 0\ J$

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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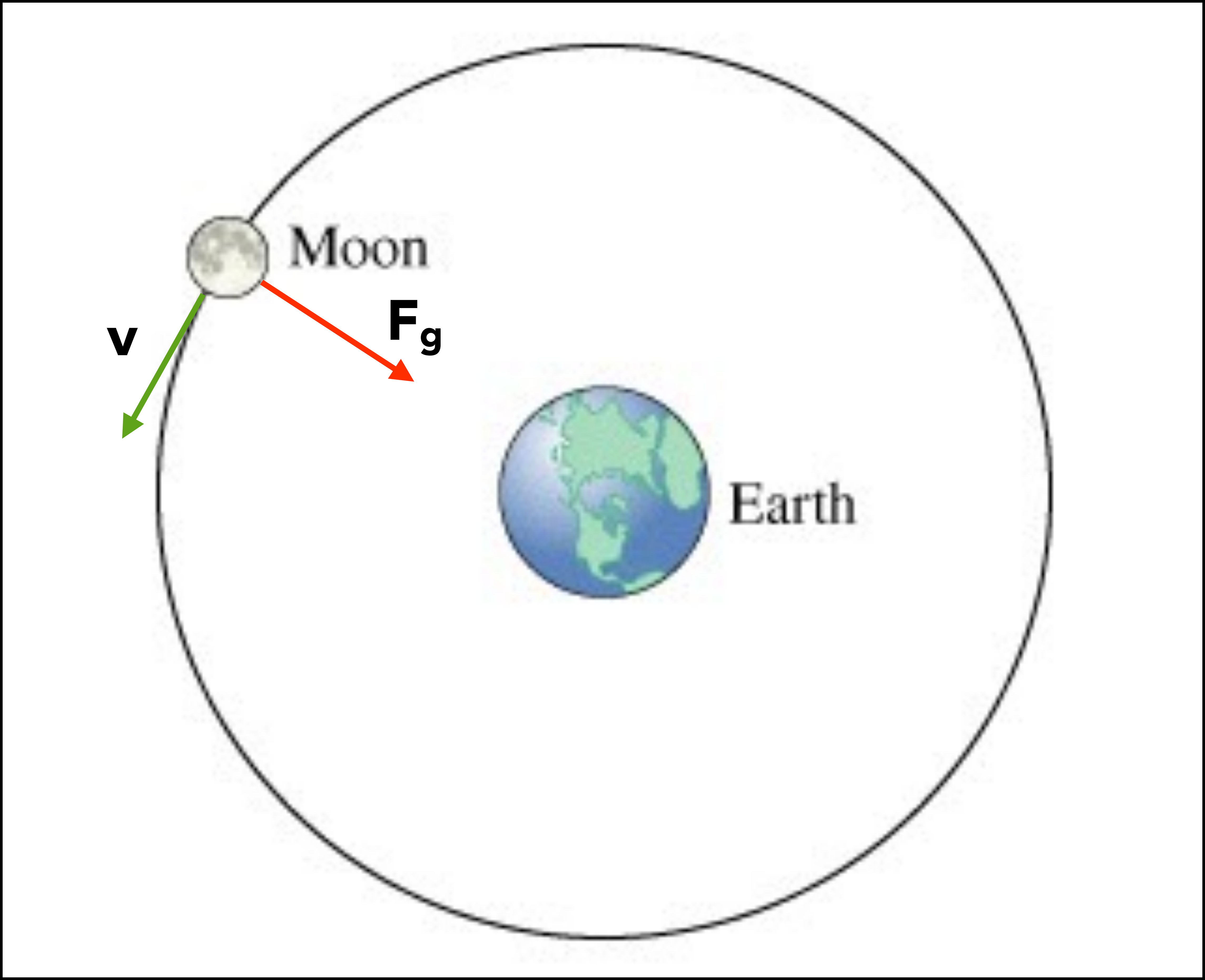
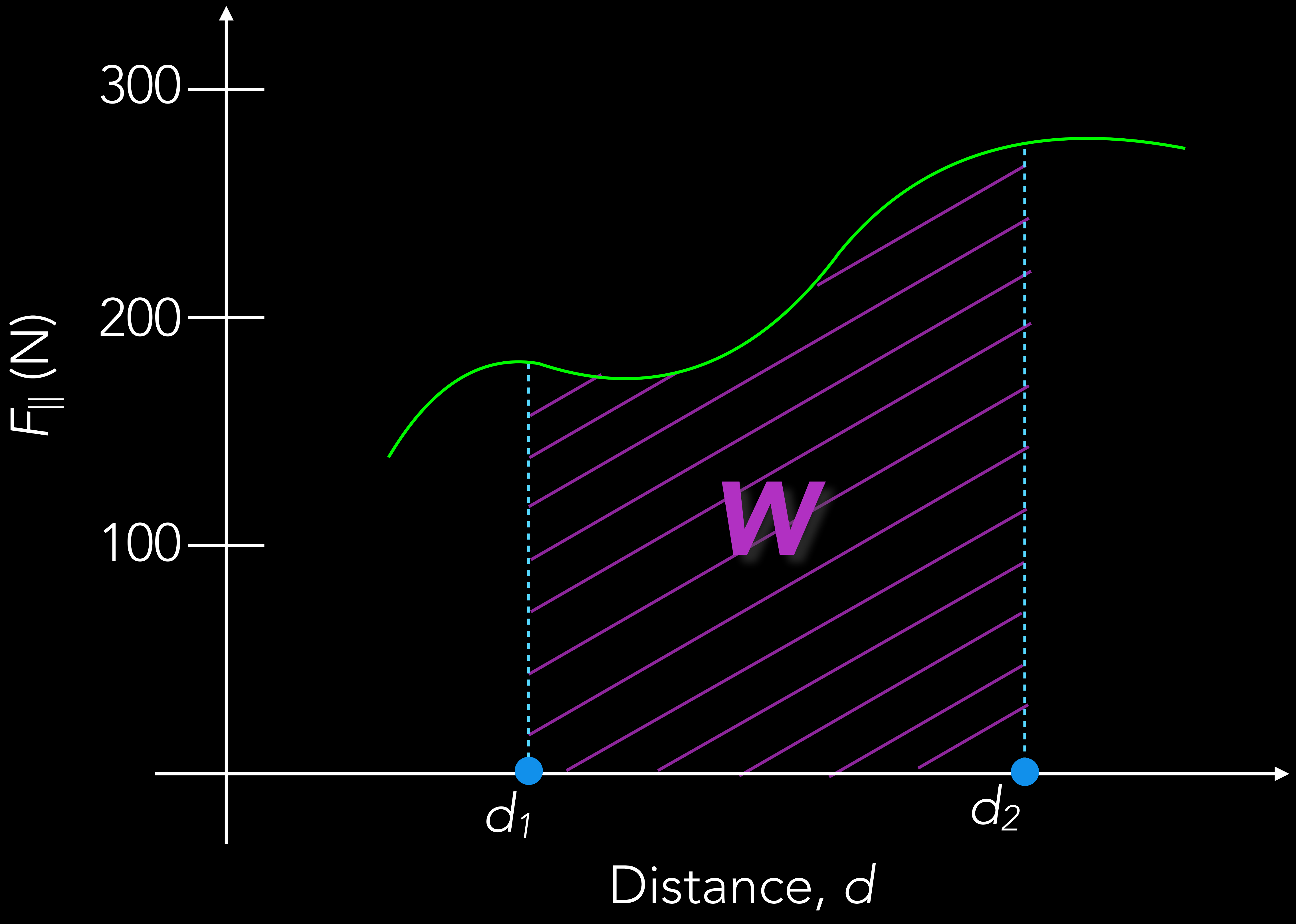

Moon
v
F_g
Earth

WORK & VARYING FORCES

- Ex. Rocket escaping Earth
- Spring when stretch or compressed
- Unevenly applied forces
- Can use graphs to find work!

$F_{||}$ vs d graph



EXAMPLE 3

- A grocery cart with mass of 18 kg is pushed at a constant speed along an aisle by a force F_A = 12 N. The applied force acts at a 20° angle with the horizontal. Find the work done by each of the forces on the cart and the net work if the aisle is 15 m long.

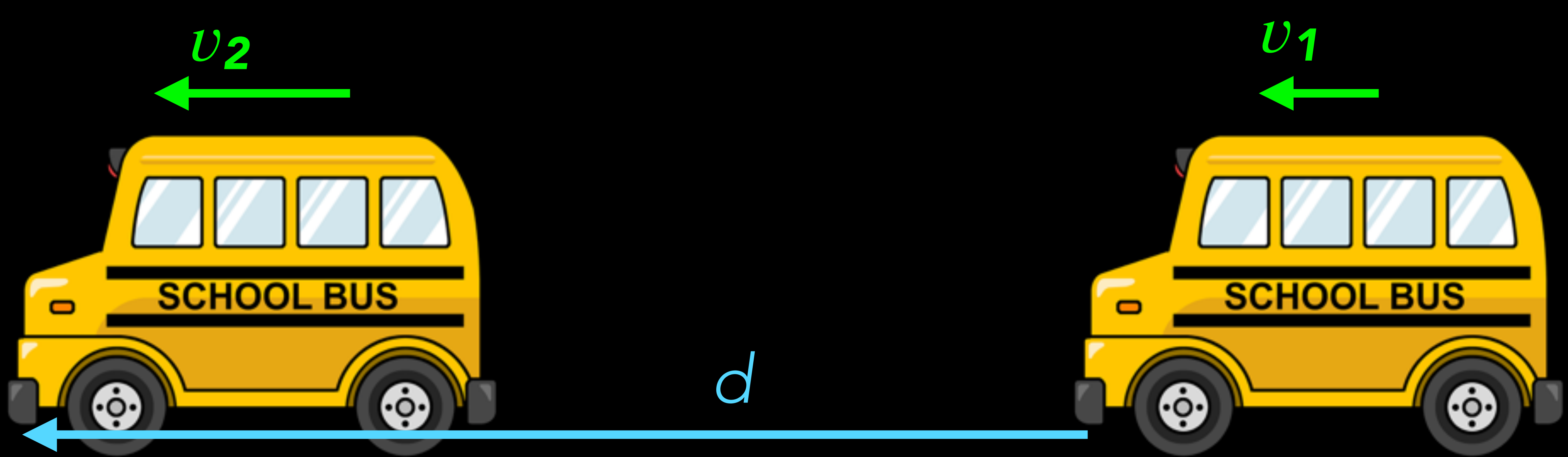
- *Ans.* $W_g = 0$ J
- $W_N = 0$ J
- $W_A = 170$ J
- $W_f = -170$ J
- $W_{net} = 0$ J

KINETIC ENERGY

- Energy is the ability to do work
- A moving object exerts a force on a second object and moves it through a distance
  - The moving object did work, thus has energy
  - Kinetic Energy is the energy of motion

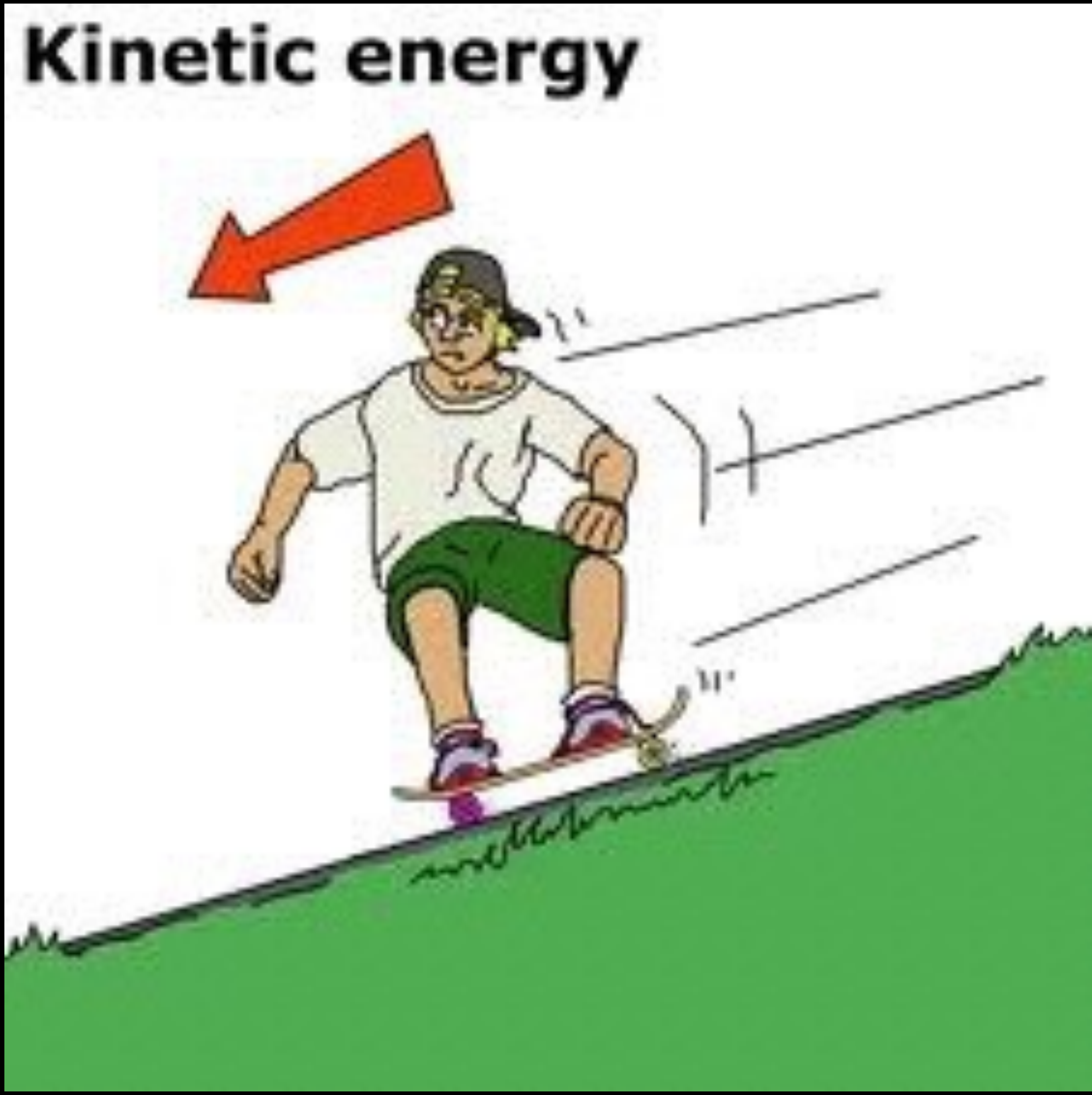
EXAMPLE 4

- A constant (but unknown) net force is exerted on a bus with mass m to accelerate it from velocity v_1 to velocity v_2 over a distance d.
- What is the net work done on the bus?
- *Ans.* $W_{net} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$



KINETIC ENERGY

- Translational kinetic energy
  - KE = ½mv^2
  - "Translational" to distinguish from rotational kinetic energy



WORK-ENERGY THEOREM

- $W_{net} = KE_2 - KE_1$

    OR

- $W_{net} = \Delta KE$
- Net work done on an object is equal to the change in its kinetic energy

WORK-ENERGY THEOREM

- Tells us that:
  - if positive net work is done on an object, its kinetic energy increases by W
  - likewise, if negative net work is done on an object, its kinetic energy decreases by W

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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EXAMPLE 5

- 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?

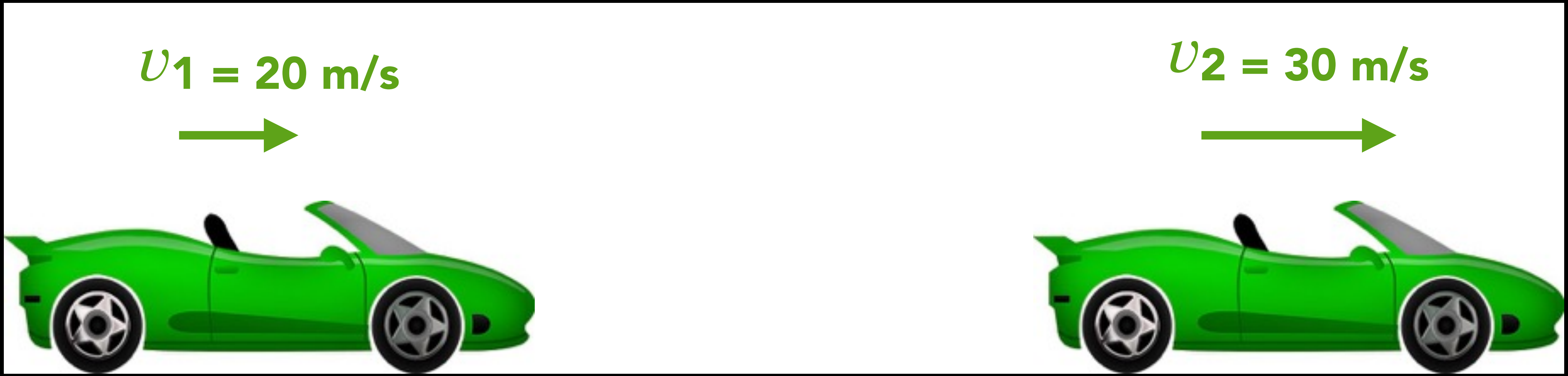
b. How much work was done on the ball to make it reach this speed if it started from rest?

- *Ans. KE = 45 J*
- $W_{net} = 45\ J$

EXAMPLE 6

- 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



EXAMPLE 7

- If traveling at 60 kph, your car can brake to a stop within a distance of 20 m.
- One morning you're running late for school, flying down the road at 120 kph, and you come up to a stop light.
- How much distance should you allow yourself brake to a halt? (The maximum braking force is approximately independent of speed)
- *Ans. 80 m*

POTENTIAL ENERGY

- Kinetic energy is how much energy an object has by virtue of its motion
- Potential energy is how much energy an object has by virtue of its 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.

GRAVITATIONAL POTENTIAL ENERGY

- A brick held above the ground has the ability to do work
    - Drop the brick, it falls under gravity and does work on, say, a stake which it drives into the ground

EXAMPLE 8

- You lift a puppy with mass *m* from the ground to a height *h*.

a. If you lift the pup at a constant velocity, how much work did you do picking it up?

b. How much work is done by gravity?

- *Ans.* $W_A = mgh$
- $W_g = -mgh$

GRAVITATIONAL POTENTIAL ENERGY

- Gravitational potential energy
  - $PE_g = mgh$
  - = weight × height *h* above some reference point
- $W_g = -\Delta PE_g$

GRAVITATIONAL POTENTIAL ENERGY

- Height *h* above what, exactly?
- You decide!
- It's the *change* in potential energy that has physical meaning since that's what's related to the work done

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

NOTE

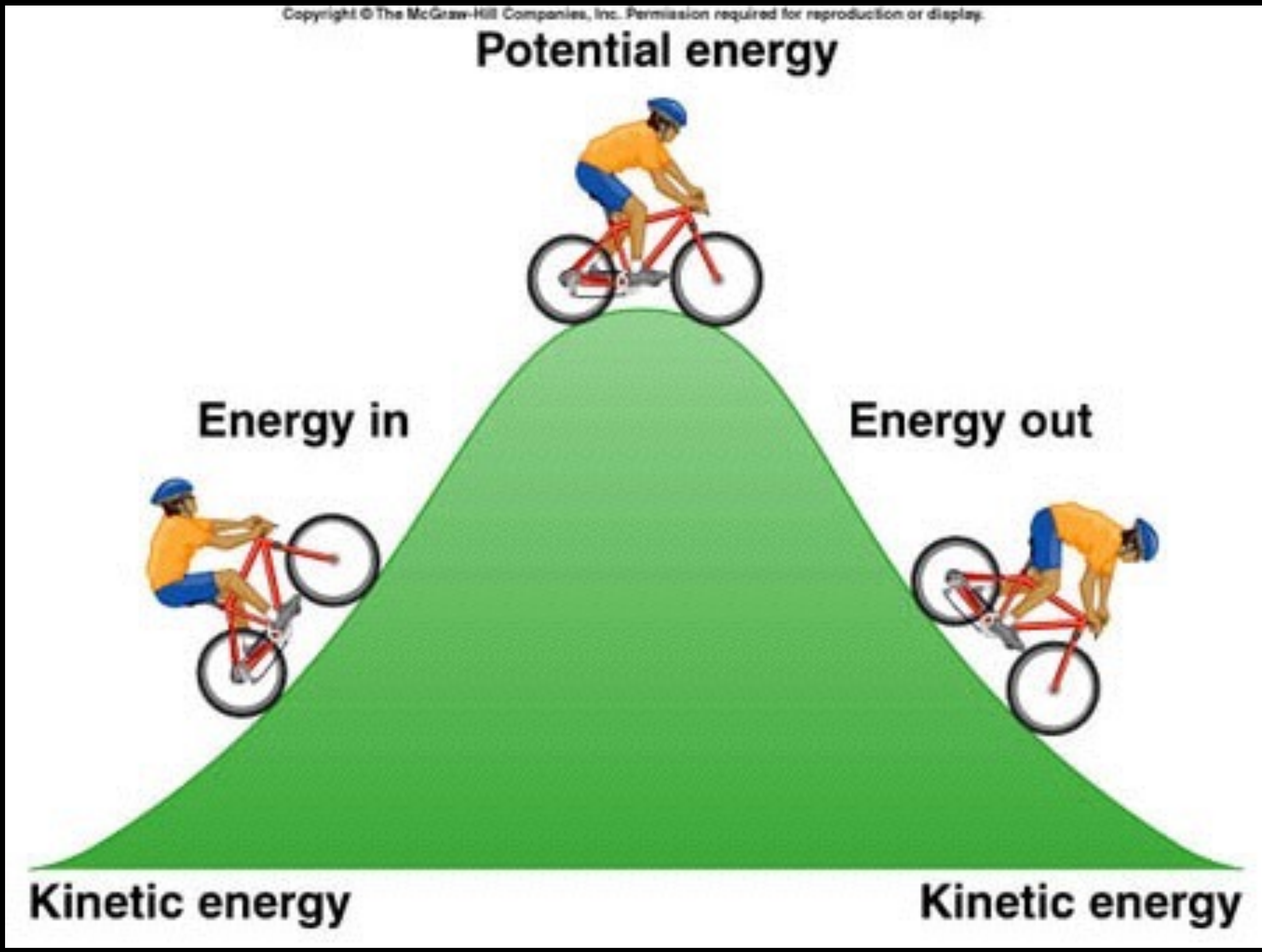
- The work done by gravity depends only on the vertical height h
- Independent of the path taken!

EXAMPLE 8B

- The puppy you were holding in example 8 wriggles free and drops to the ground.
- If it started from rest, what will be its kinetic energy when it reaches the floor?
- *Ans.* $KE = mgh$

MOVEMENT OF ENERGY

- Energy cannot be created or destroyed, just shuffled around
- Ex.8b: $PE_g \Rightarrow KE$



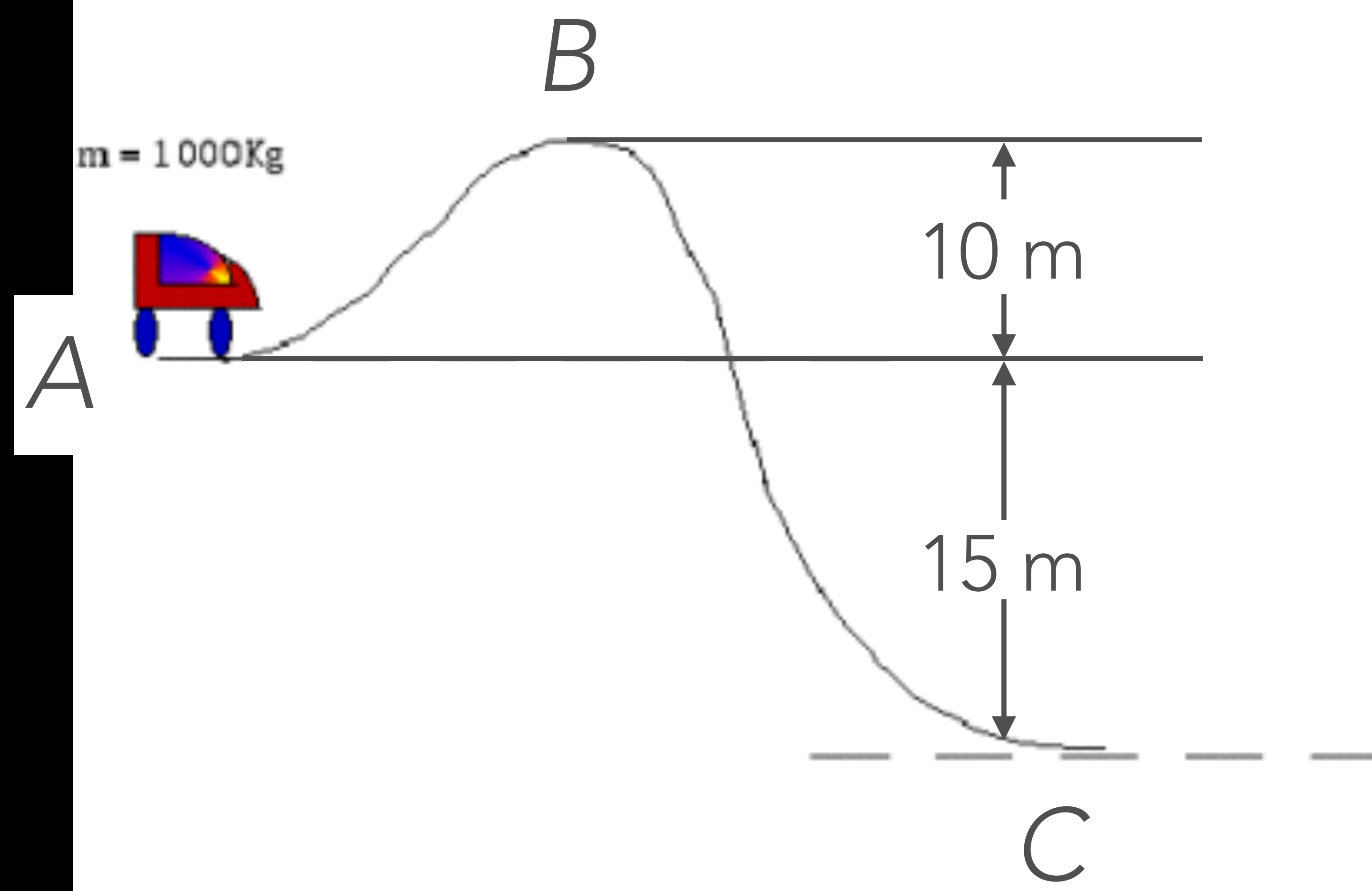
EXAMPLE 9

- A 1000-kg roller-coaster car moves from point *A* to point *B* and then to point *C*.

a. What is its gravitational potential energy at *B* and *C* relative to point *A*? (Take y = 0 at point *A*)

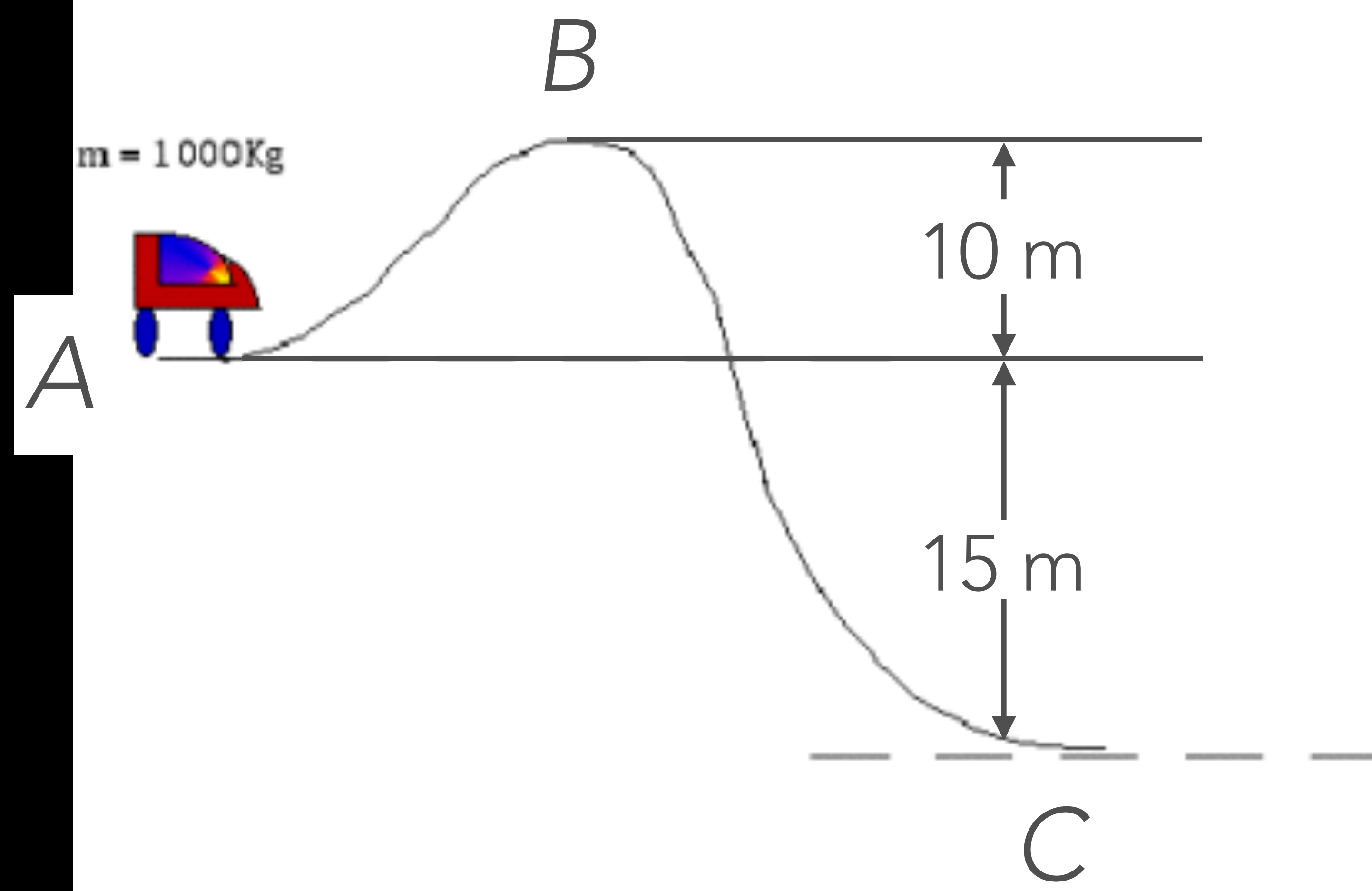
b. What is the change in potential energy when it goes from *B* to *C*?

- *Ans.* $PE_B = 9.8\times10^4$ J
- $PE_C = -1.5\times10^5$ J
- $\Delta PE = -2.5\times10^5$ J



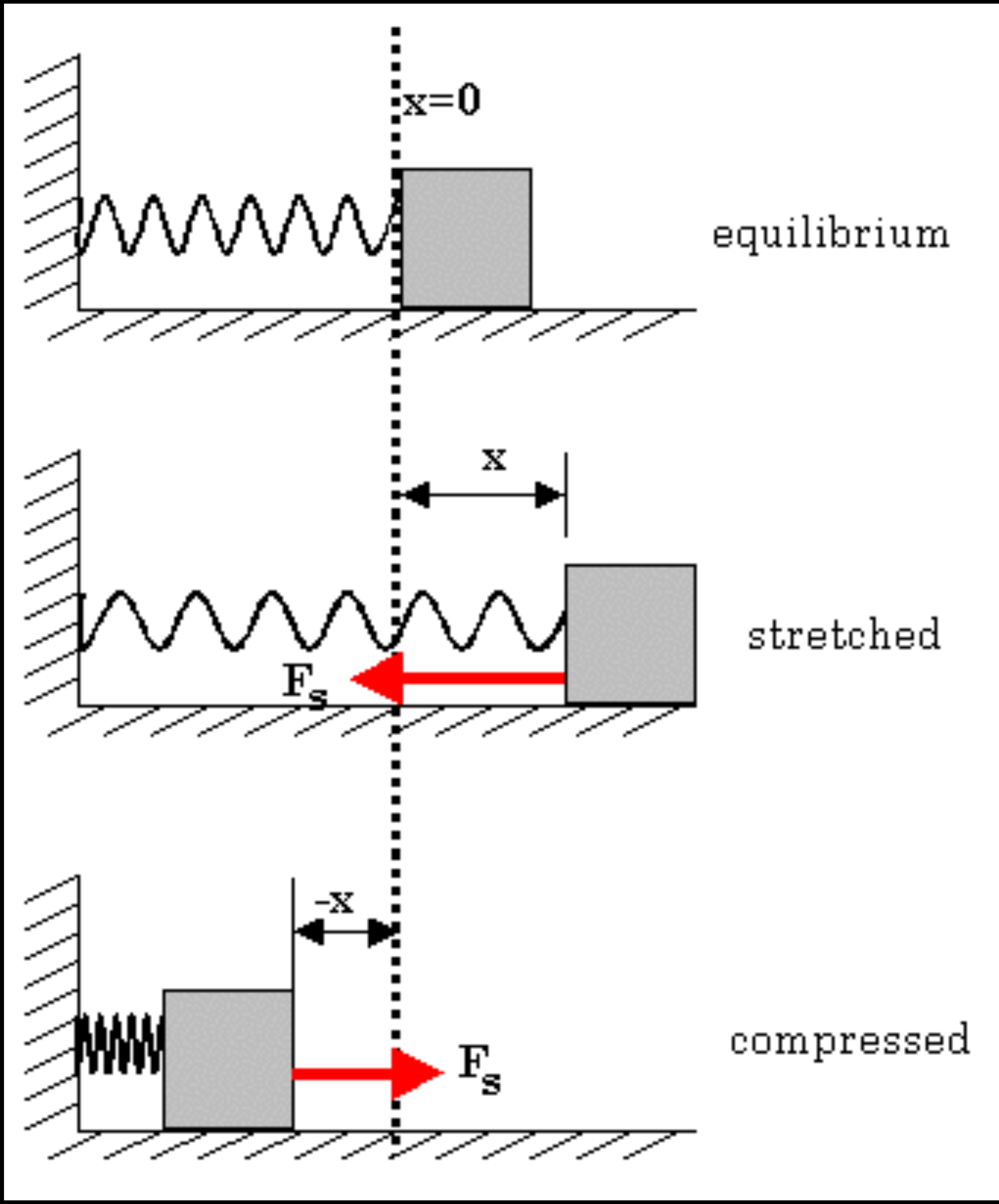
EXAMPLE 9B

- Repeat Ex.9 but take the reference point ($y = 0$) to be at point *C*
- *Ans.* $PE_B = 2.5 \times 10^5\ J$
- $PE_C = 0\ J$
- $\Delta PE = -2.5 \times 10^5\ J$



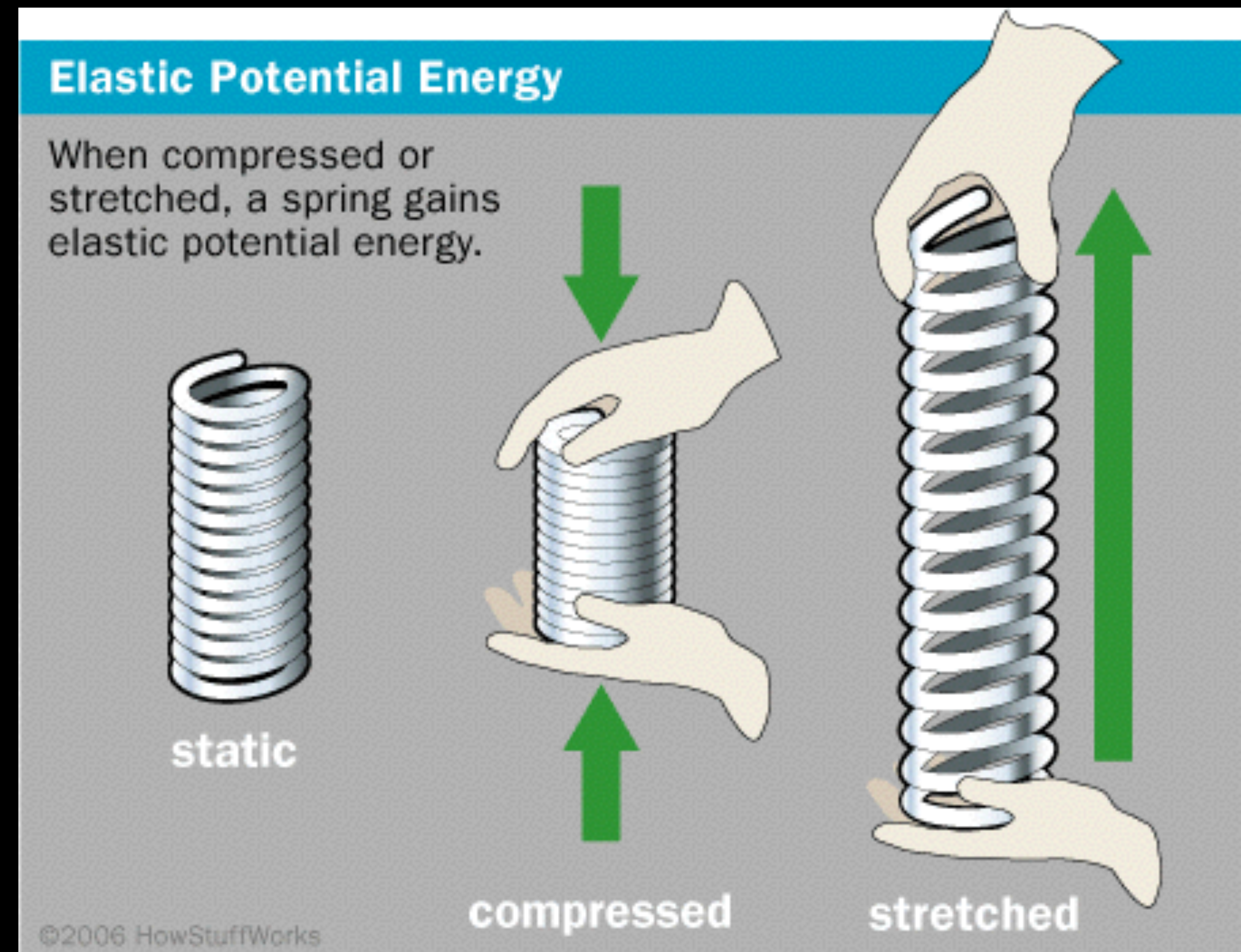
SPRING FORCE

- Hooke's Law:
  - $F_S = -kx$
  - k = spring constant
    - measure of stiffness (in N/m)
  - x = stretch or compress displacement
  - negative because force is opposite displacement
    - "restoring force"



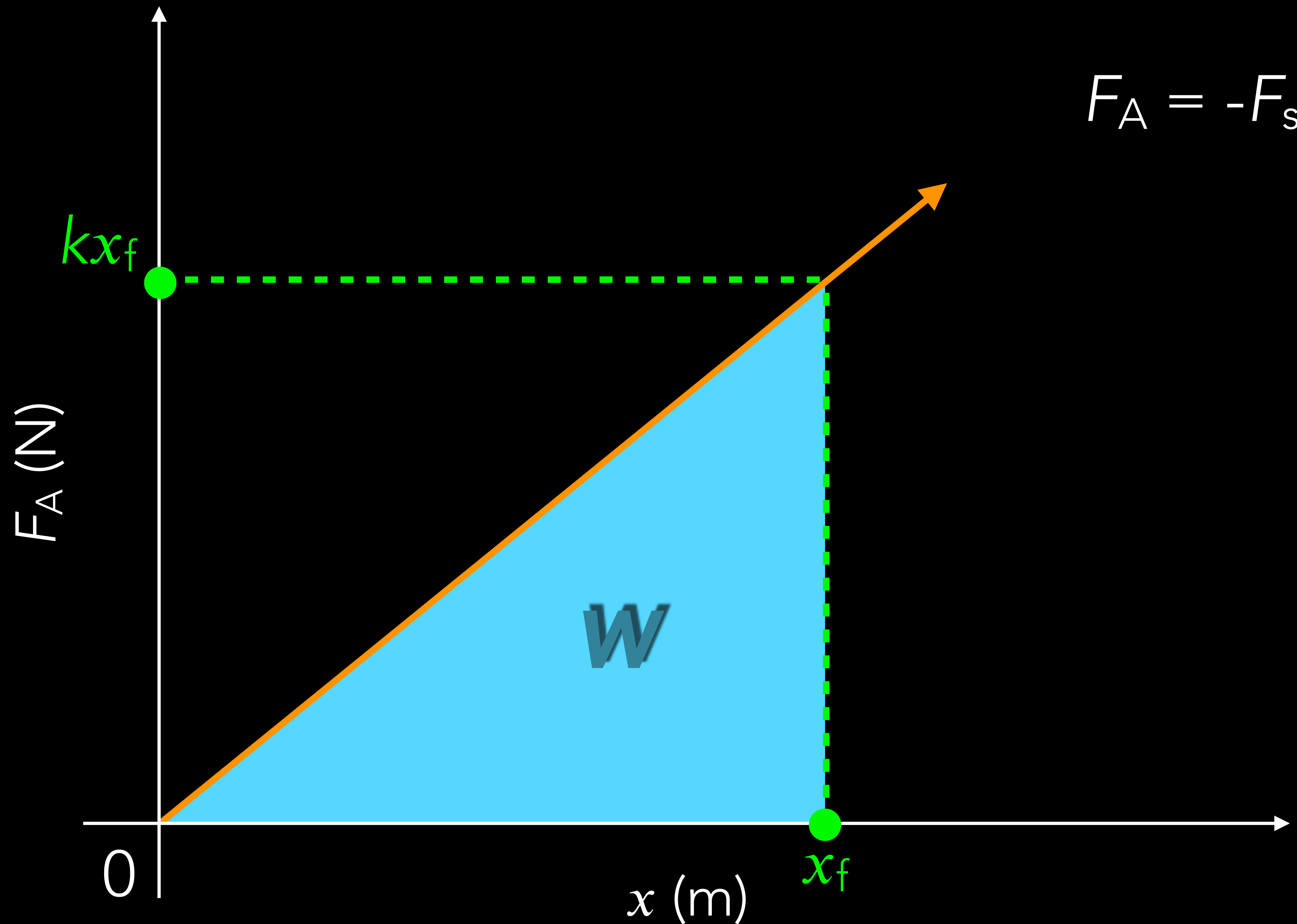
ELASTIC POTENTIAL ENERGY

- How much work is needed to stretch a spring?
  - <u>*Not*</u> $W = F_S x$
  - Why?



F_A vs x

$F_A = -F_s = kx$



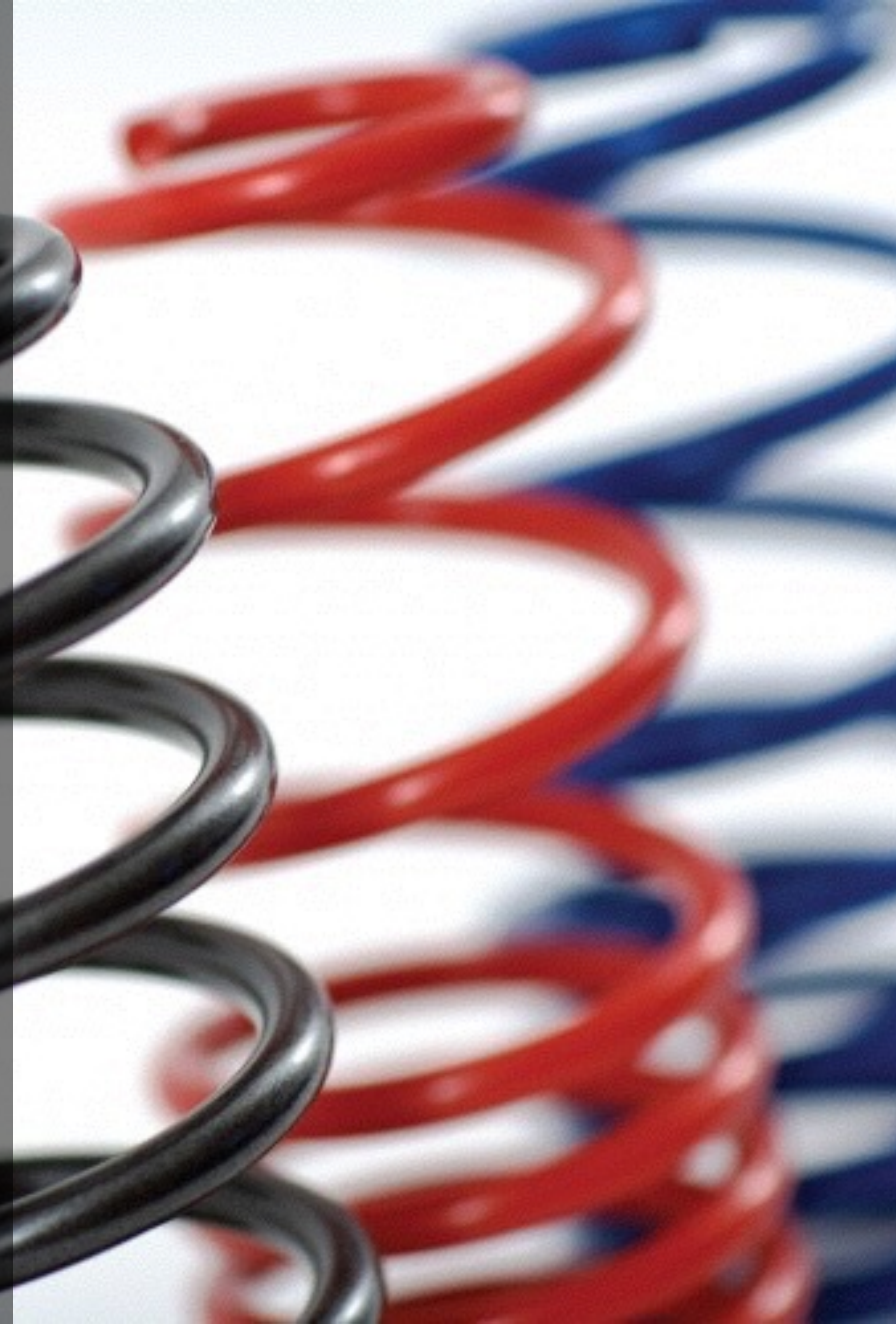
ELASTIC POTENTIAL ENERGY

- Elastic potential energy
  - $PE_E = \frac{1}{2} kx^2$

EXAMPLE 10

- A spring has a spring constant, *k*, of 440 N/m. How much must this spring be stretched to store 25 J of potential energy?

- *Ans.* x *= 34 cm*



CONSERVATIVE FORCES

- Work done against gravity does *not* depend on the path taken

- Forces for which the work done does not depend on the path taken but only on the initial and final positions are called conservative forces

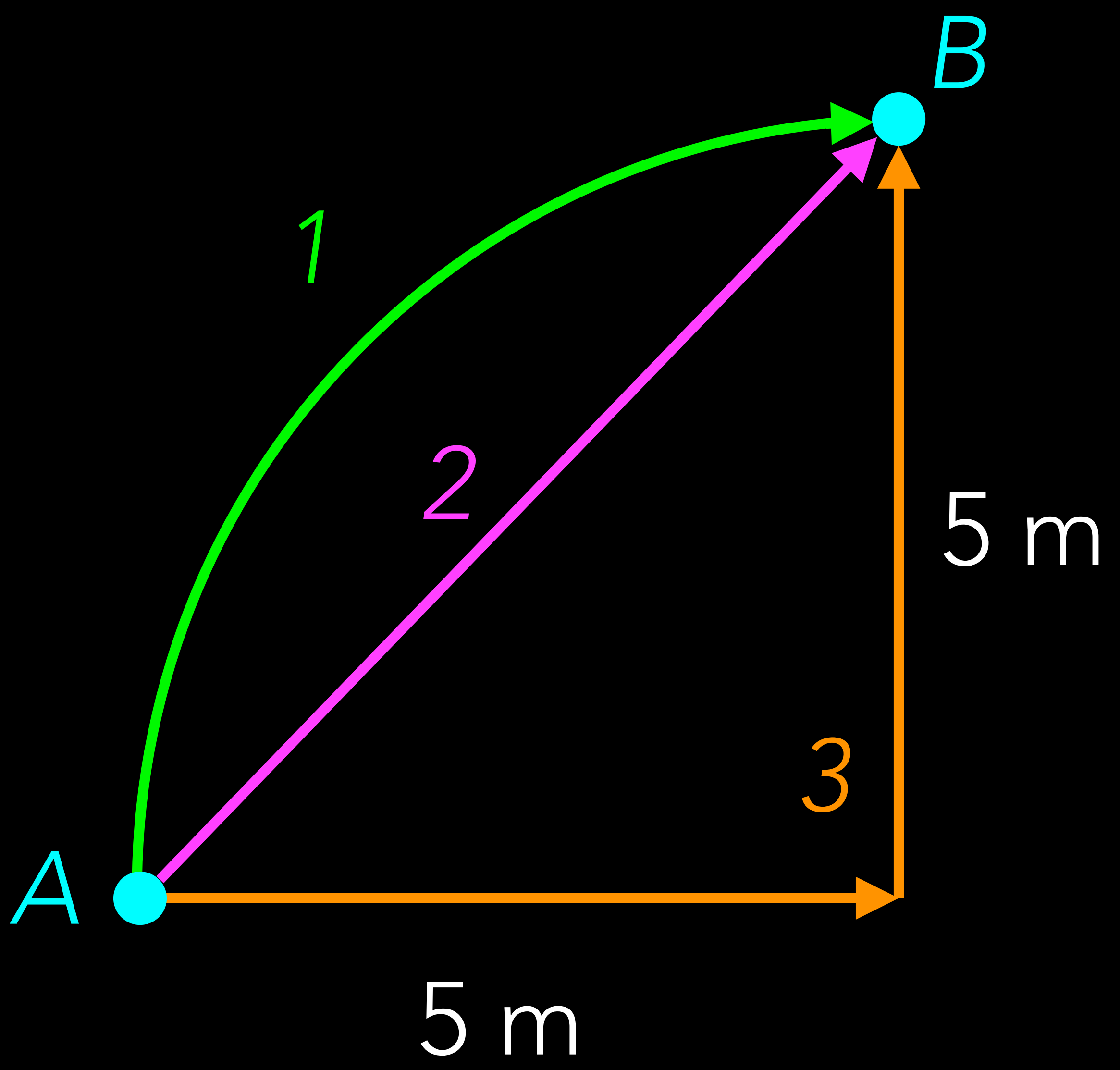
    - E.g. gravitational, elastic, electric

NONCONSERVATIVE FORCES

- Nonconservative forces *do* depend on the path
  - E.g. friction, air resistance, tension, push or pull from a person

EXAMPLE 11

- 50 N of friction act on a box as its dragged across the floor from *A* to *B*. How much work is done by friction along the three paths shown to the right?
- *Ans.* $W_1 = -393\ J$
- $W_2 = -354\ J$
- $W_3 = -500\ J$



CONSERVATIVE FORCES & POTENTIAL ENERGY

- Potential energy is the energy associated with position or configuration
  - Only makes sense if it can be stated uniquely for a given point
  - This can't be done with nonconservative forces (depend on position *and* path)
- *Potential energy can be defined only for a conservative force*

WORK-ENERGY THEOREM

- $W_{net} = W_C + W_{NC}$
  - $W_{net} = \Delta KE$
  - $W_C = -\Delta PE$
- $W_{NC} = \Delta KE + \Delta PE$
- *Note: make sure to include every force acting on the system*

CONSERVATION OF MECHANICAL ENERGY

- What if there are no nonconservative forces acting on the system?
- $\Delta KE + \Delta PE = 0$
- $(KE_2 - KE_1) + (PE_2 - PE_1) = 0$
- $KE_2 + PE_2 = KE_1 + PE_1$
- Total mechanical energy, E
  - $E = KE + PE$
  - $E_2 = E_1 = \text{constant}$

CONSERVATION OF MECHANICAL ENERGY

- If only conservative forces are acting, the total mechanical energy of a system neither increases nor decreases in any process. It stays constant — it is conserved

EXAMPLE 12

- A 65 kg skydiver drops out of an airplane from an altitude of 4.0 km and opens her parachute when she's 650 m above the ground.
- Using conservation of energy, calculate her speed the moment before she launches the parachute (neglect air resistance)
- *Ans. 260 m/s*

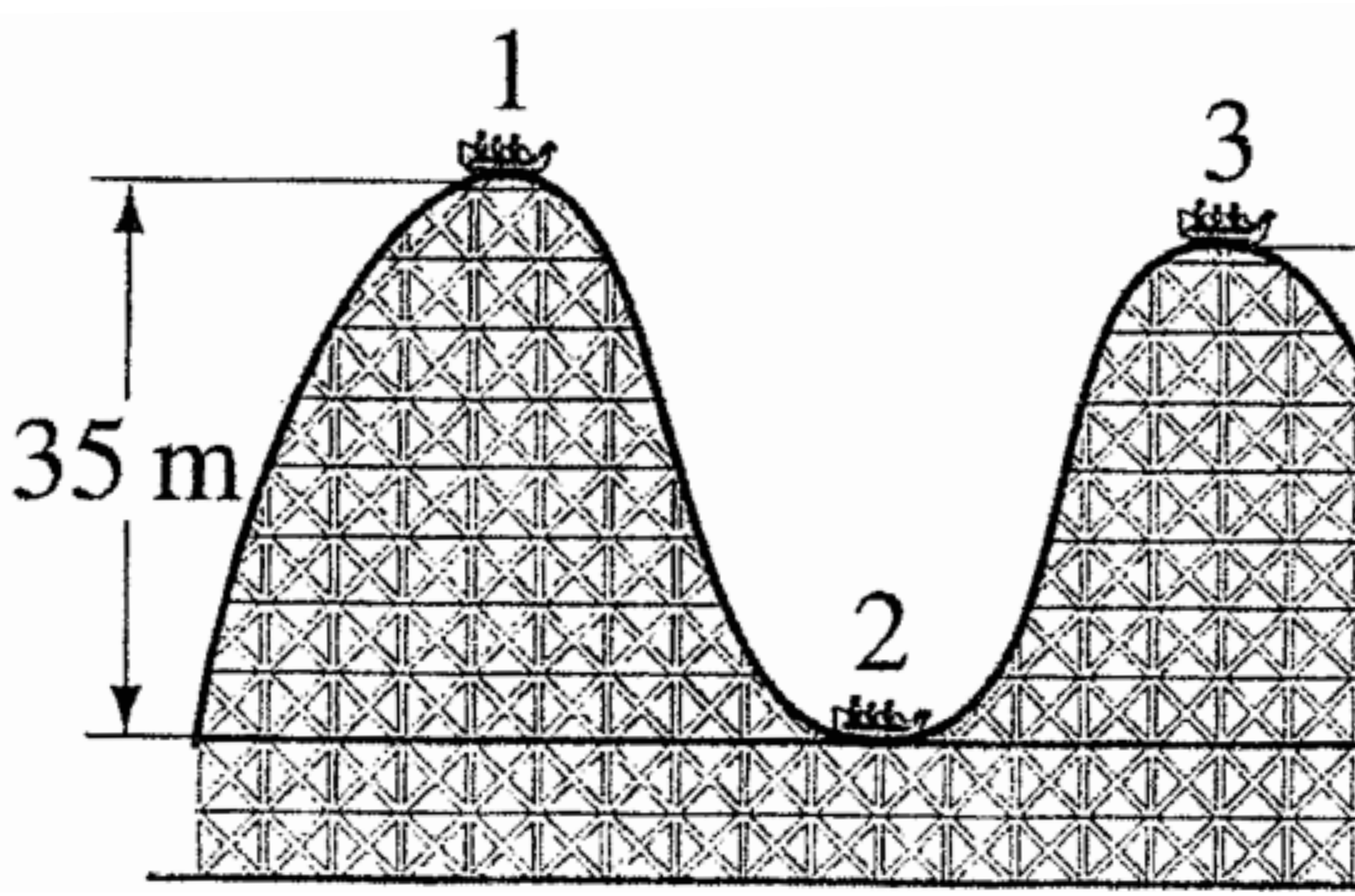
EXAMPLE 13

- A rollercoaster car flies along at 25 m/s before dropping down a 35 m hill.

a. What will be the speed of the car at the bottom of the hill?

b. What is the maximum height of the second hill the car could make it up without assistance?

- *Ans.* $v_2 = 36$ *m/s*
- $h_{max} = 67$ *m*



EXAMPLE 14

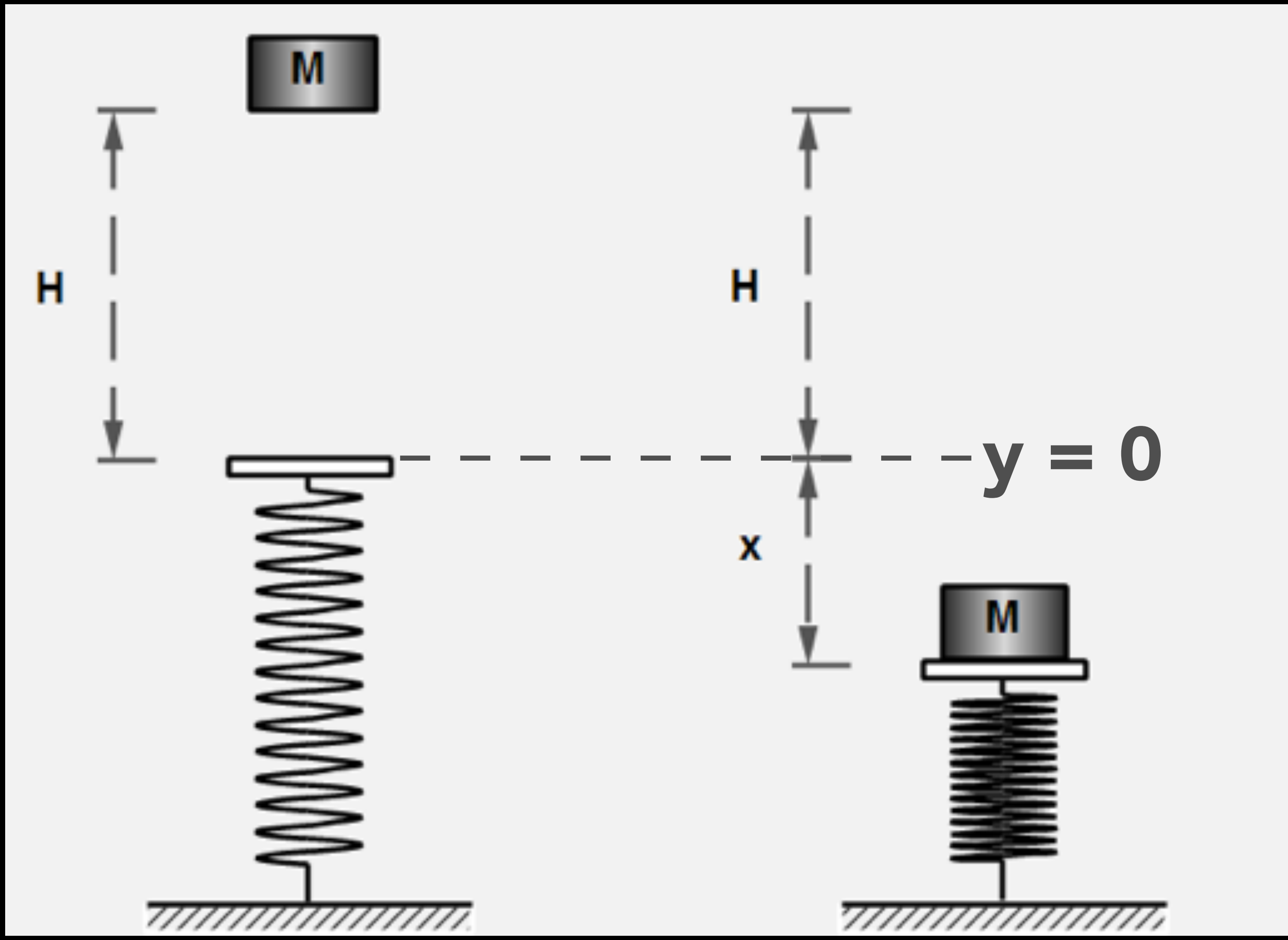
- A team of three brilliant JPL engineers built a slingshot to launch a 850. g lander through the skies. They load the pyramidal lander, pull the bungee cord (k_{eff} = 53.4 N/m) back 1.2 m, and let 'er rip!

- What speed will the lander acquire when launched?

- *Ans.* v *= 9.51 m/s*

EXAMPLE 15

- A block of mass $M = 2.60$ kg, starting from rest, falls a vertical distance $H = 55.0$ cm before striking a vertical coiled spring, which it compresses an amount $x = 15.0$ cm. Determine the spring constant of the spring. Assume the spring has negligible mass.



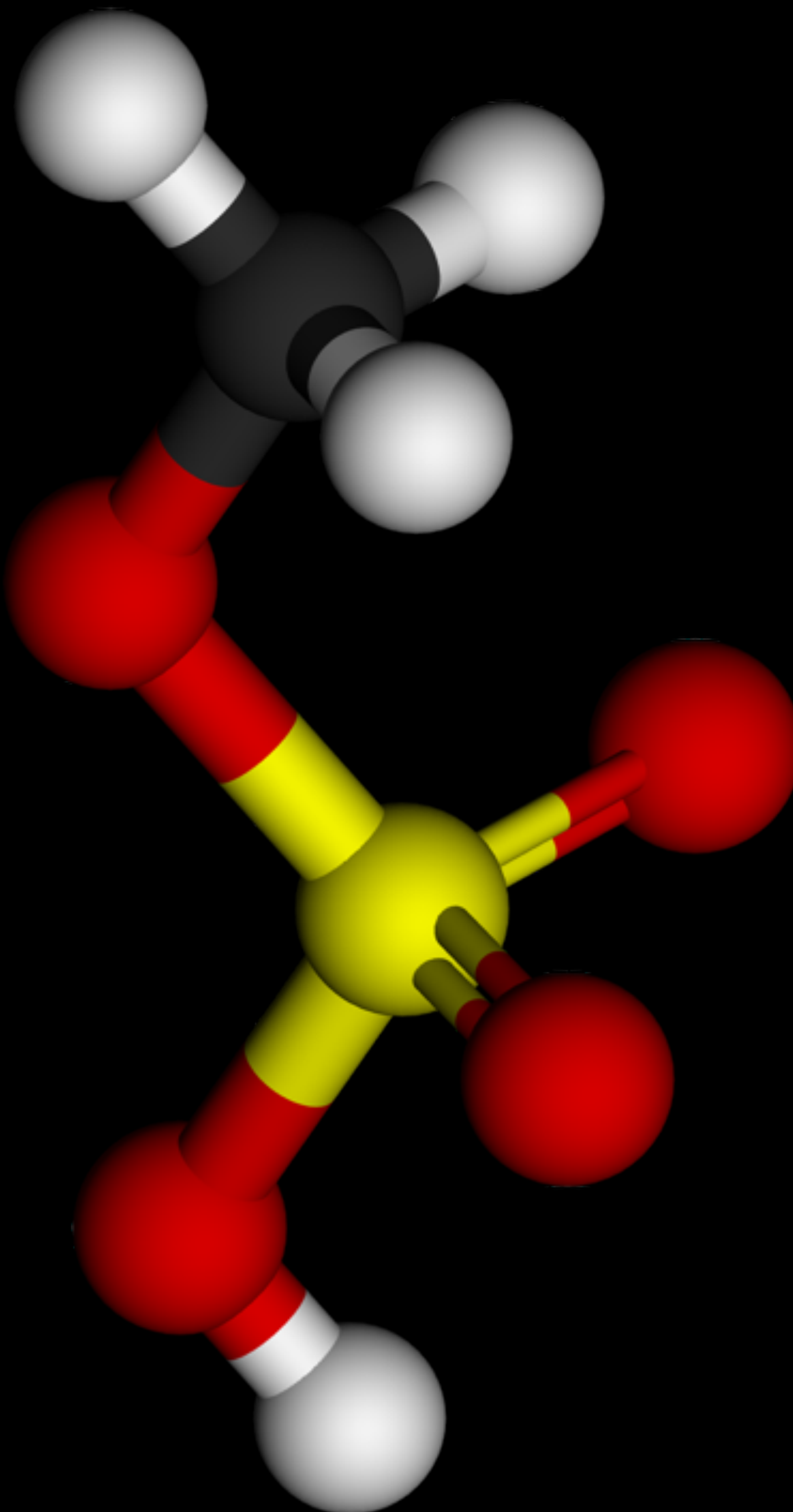
- *Ans. k = 1580 N/m*

OTHER FORMS OF ENERGY

- Electric, nuclear, thermal, and chemical energy
    - All actually either kinetic or potential energy at the atomic or molecular level
- E.g. thermal energy is KE of of rapidly moving atoms or molecules
    - When heating an object, the molecules that make it up move around faster

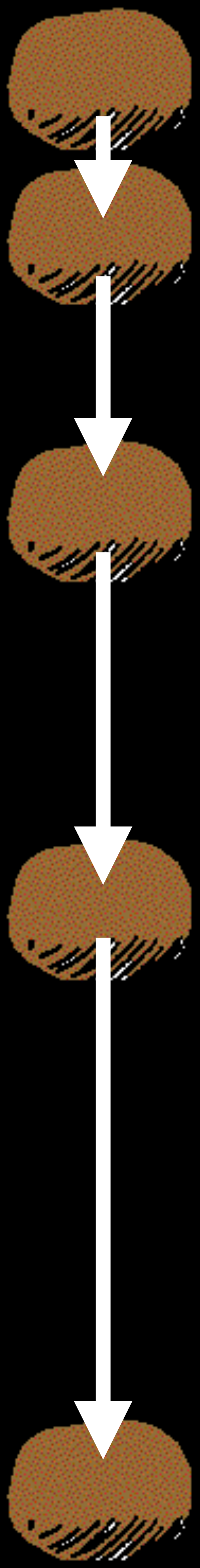
OTHER FORMS OF ENERGY

- 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



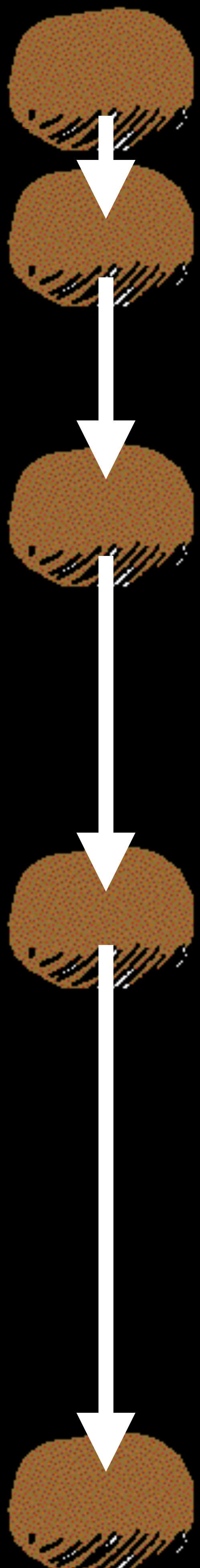
ENERGY TRANSFORMATION

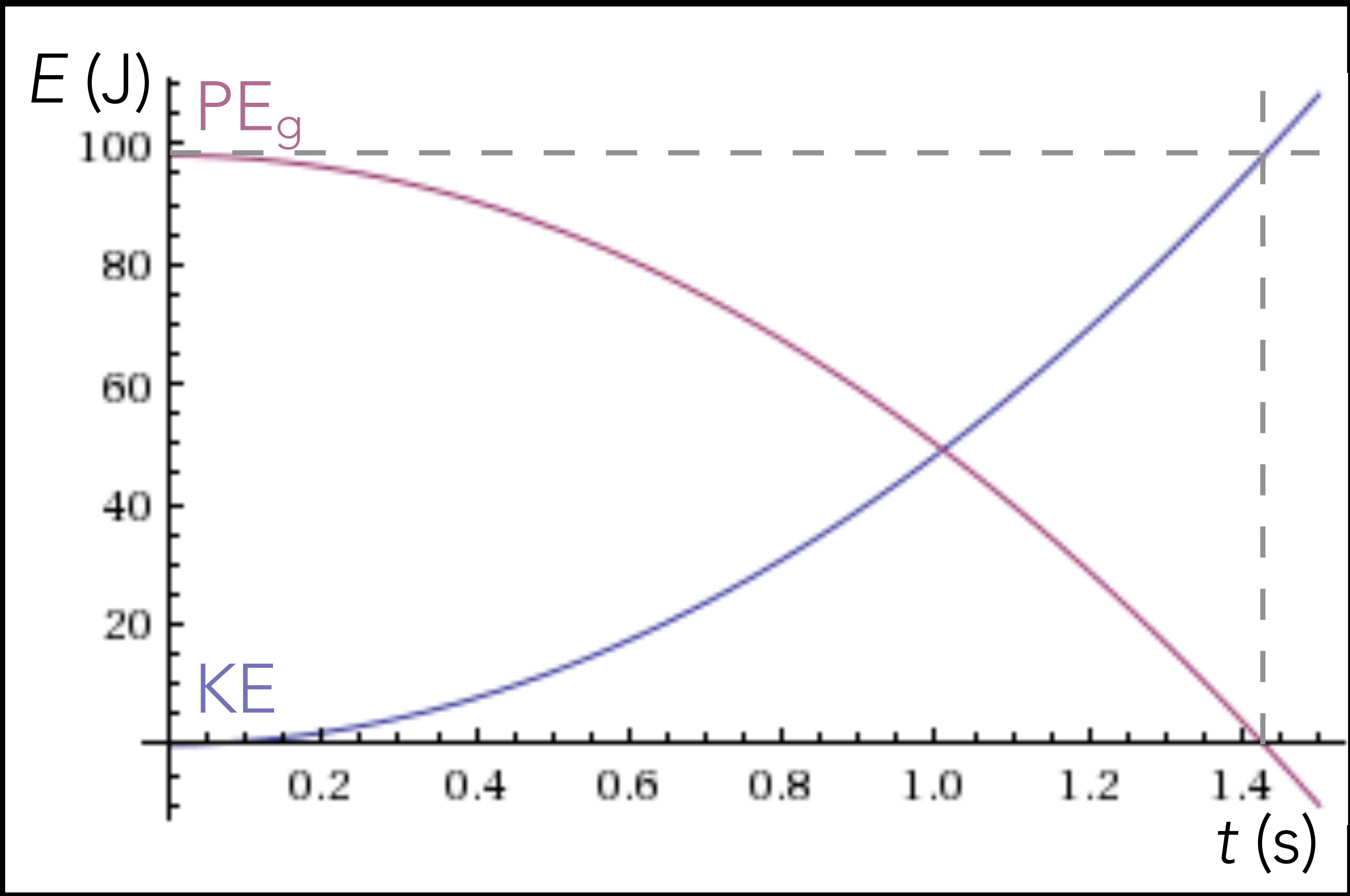
- Stone in free fall:
  - begins at rest — PE_g
  - picks up speed/loses height — $PE_g + KE$
  - hits the ground (nearly) — KE



ENERGY TRANSFORMATION: FREE FALL

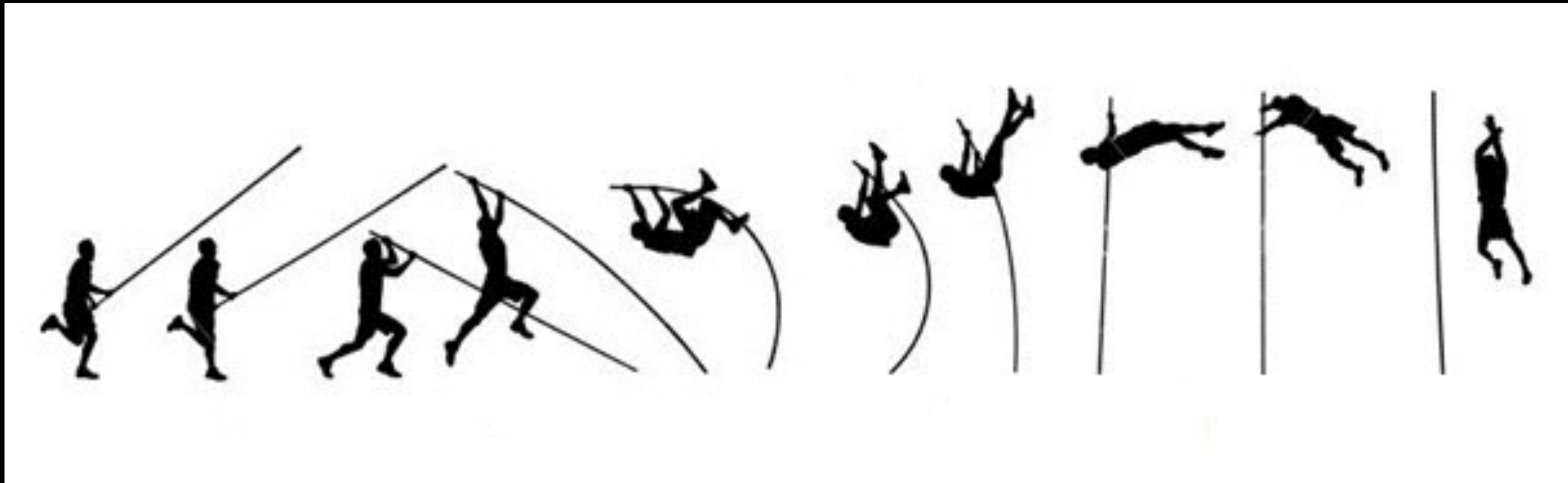
$m = 1\text{ kg},\ h = 10\text{ m}$





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



ENERGY TRANSFORMATION

- 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

DISSIPATIVE FORCES

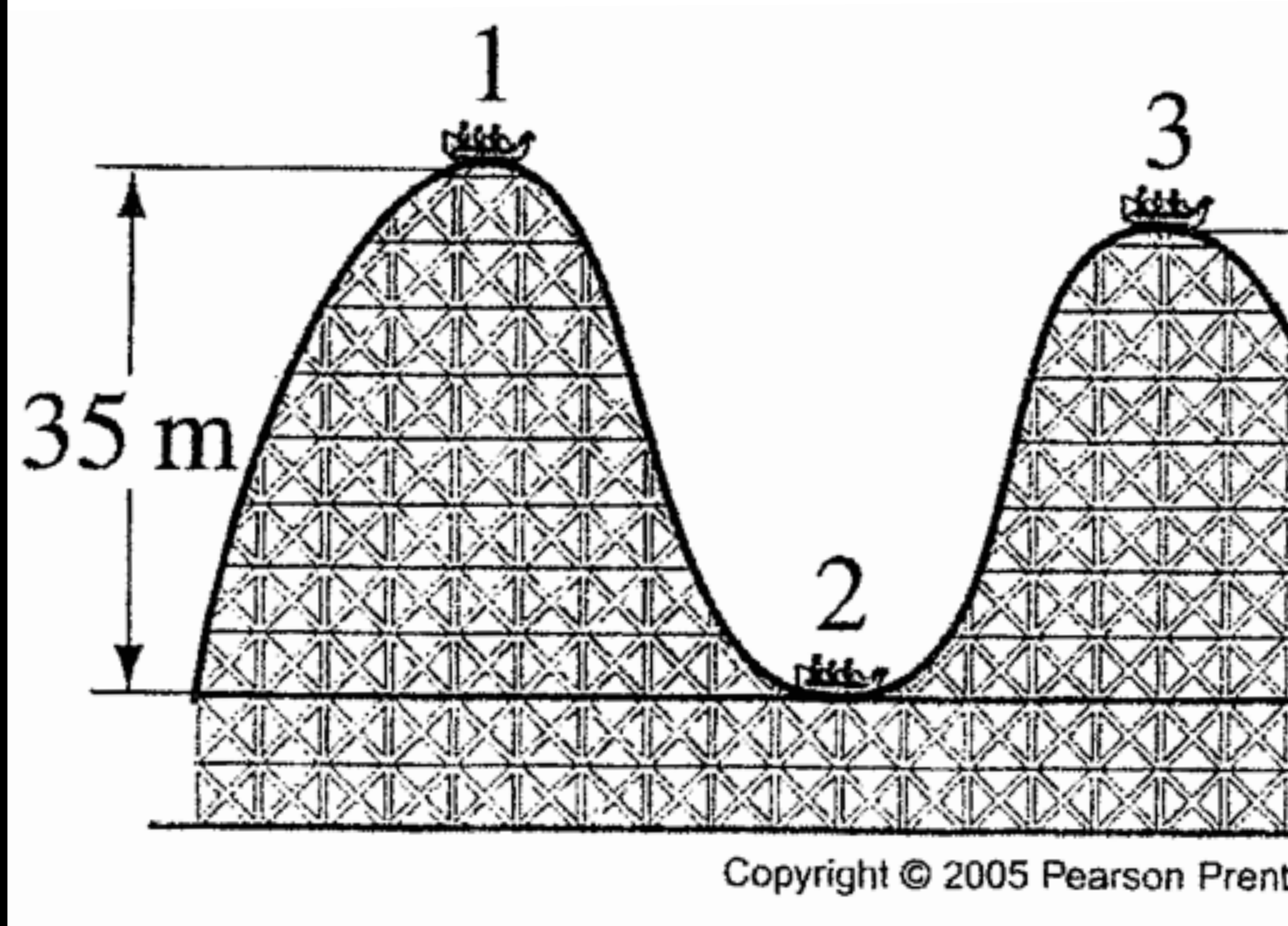
- Before, we've done conservation of energy neglecting friction (nonconservative forces)
- What if we include it?
- In all natural processes, the mechanical energy does *not* remain constant but *decreases*
- Because frictional forces reduce the total mechanical energy, they are called dissipative forces

DISSIPATIVE FORCES

- Friction looses energy as heat, or thermal energy
- If you include thermal energy, then the total energy is conserved
- $W_{NC} = \Delta KE + \Delta PE$
- Conservation of energy with gravity and friction:
  - $\frac{1}{2}mv_1^2 + mgy_1 = \frac{1}{2}mv_2^2 + mgy_2 + fd$

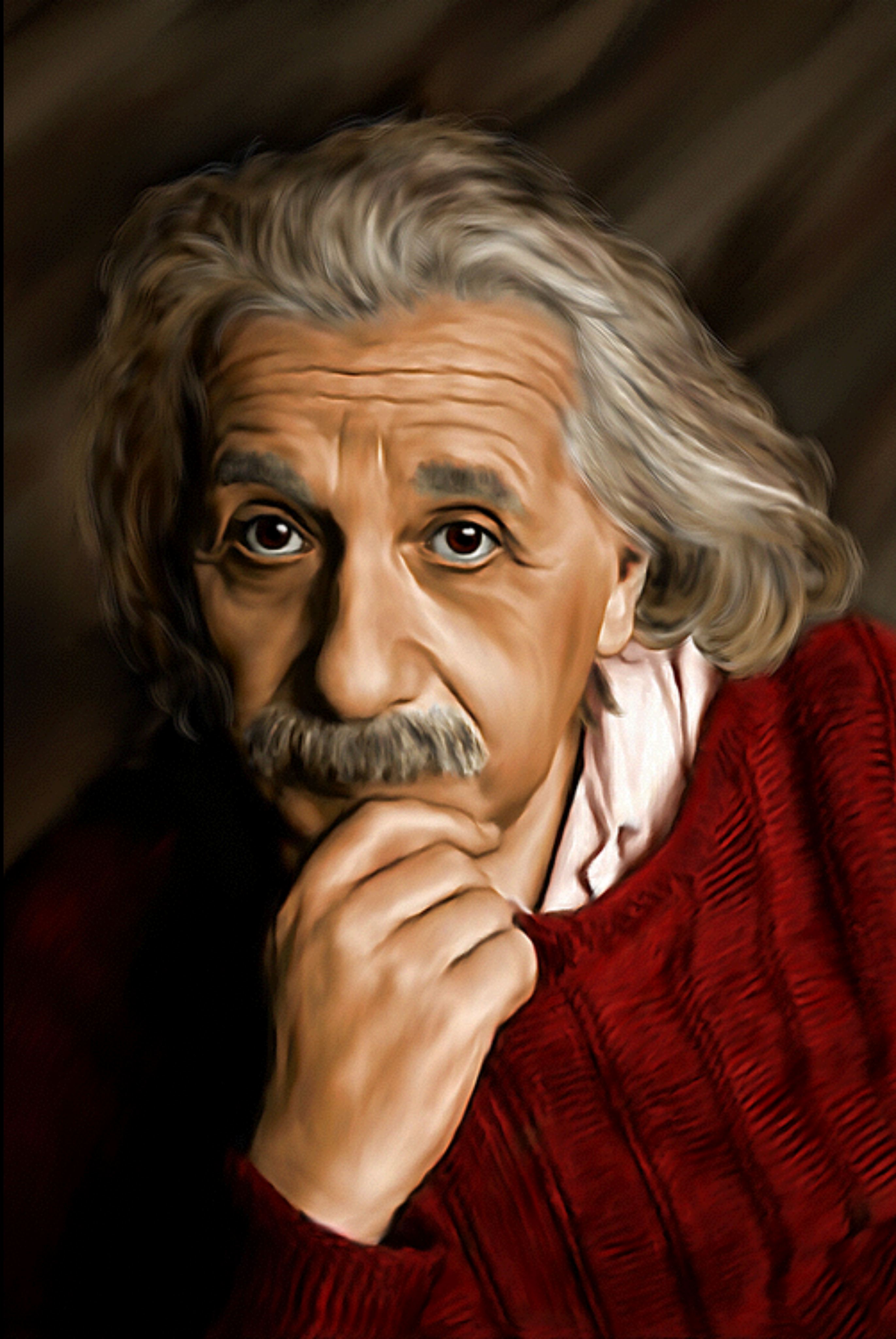
EXAMPLE 16

- Like ex. 13, a rollercoaster car is traveling at 25.0 m/s before descending down the 35.0 m drop.
- This time, however, the car only makes it to a vertical height of 50.0 m up the second hill.
- If it traveled a total distance of 400. m, estimate the average friction force on the car whose mass is 1000. kg.
- *Ans. f = 413 N*



MASS ENERGY

- In 1905, Albert Einstein was the first to propose the equivalence between mass and energy
- All objects with mass have intrinsic, internal energy just by virtue of their existence
- $E = mc^2$
  - c is the speed of light
  - $c = 3.00\times10^8$ m/s



EXAMPLE 17

- What is the mass energy of a 1.0 g peanut?
  - *Ans. 90. TJ*
- What is the mass energy of a 60. kg person?
  - *Ans.* 5.4×10^{18} *J*

MASS ENERGY

- Because mass and energy are equivalent, one can be converted to the other
- This is the principle behind nuclear reactors
  - Heavy and unstable uranium or plutonium absorb a neutron
  - In a process called nuclear fission, the nucleus of the atom splits up into two or more lighter elements
  - Through this process, it gives up some of its mass energy as kinetic energy, thermal energy, and radiation

MASS ENERGY

- This same science, however, also allowed us to create the atomic bomb
- During WWII, *Little Boy* and *Fat Man* unleashed 63 - 88 TJ each, decimating the cities of Hiroshima and Nagasaki

POWER

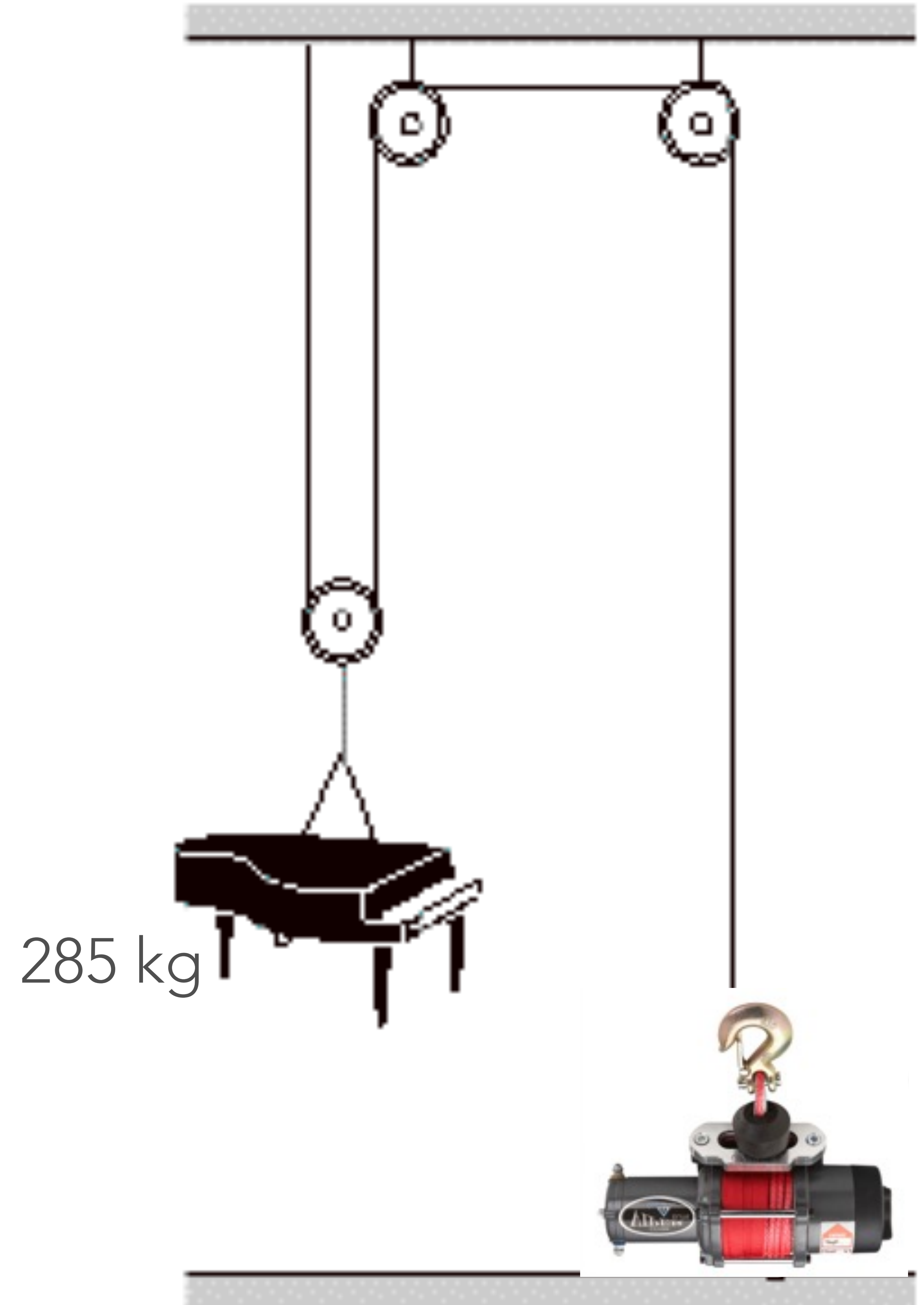
- Average power is the *rate at which work is done*
- or the *rate at which energy is transformed*
- $P = W/t$
- Measured in watts (W)
  - 1 W = 1 J/s

POWER

- A 40 W lightbulb transforms 40 J of electrical energy into light and heat energy every second
- My Toyota Camry has a 250 horsepower engine
  - 1 hp = 746 W
  - 250 hp = 186.5 kW

EXAMPLE 18

- How long will it take a 1750-W motor to lift a 285-kg piano to a sixth-story window 16.0 m above?
- *Ans. $t = 25.6$ s*



SANITY CHECK

- The Nova laser at Lawrence Livermore National Lab has ten beams, each of which has a power output greater than that of all the power plants in the United States. Where does this power come from?

POWER & CARS

- Cars and trucks have to do work to overcome the force of friction and air resistance, to climb hills, and to accelerate
- Retarding forces, such as internal friction and air resistance, are typically 400-1000 N
- Often convenient to write power in terms of net force applied to an object and its average speed v
- $P = W/t = Fd/t = Fv$

EXAMPLE 19

- Calculate the power required of a 1400-kg car under the following circumstances, assume the total retarding force on the car F_R = 700 N:

a. the car climbs a 10° hill at a steady 80 kph

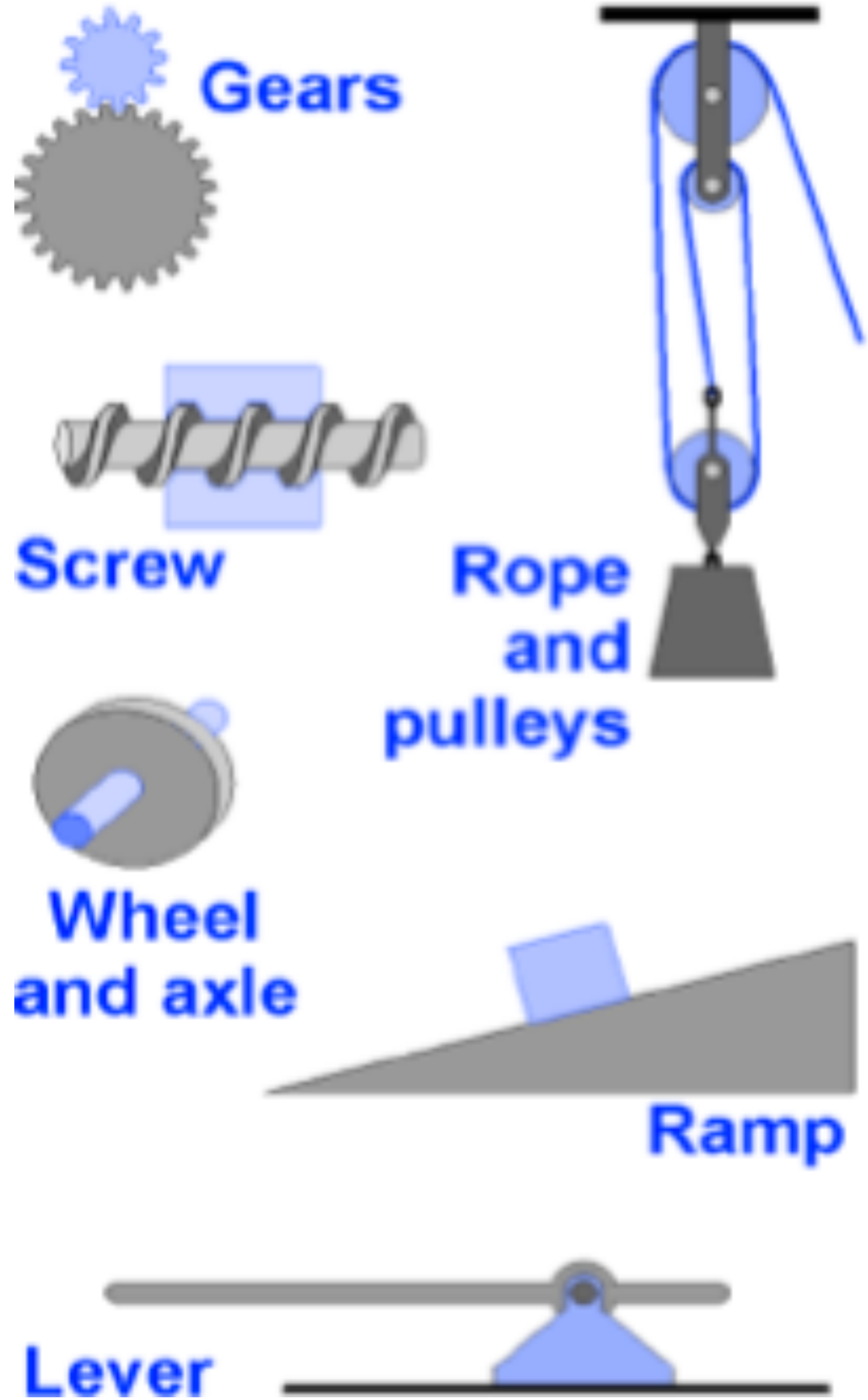
b. the car accelerates along a level road from 90 to 110 kph in 6.0 s to pass another car

  a. *Ans.* $P = 6.80\times10^4$ W = 91 hp

  b. *Ans.* $P = 6.12\times10^4$ W = 82 hp

MACHINES

- Machines are designed to take advantage of the relationship between work, force, and distance
- Simple machines are devices that use only the forces directly applied and accomplish their task with a single motion

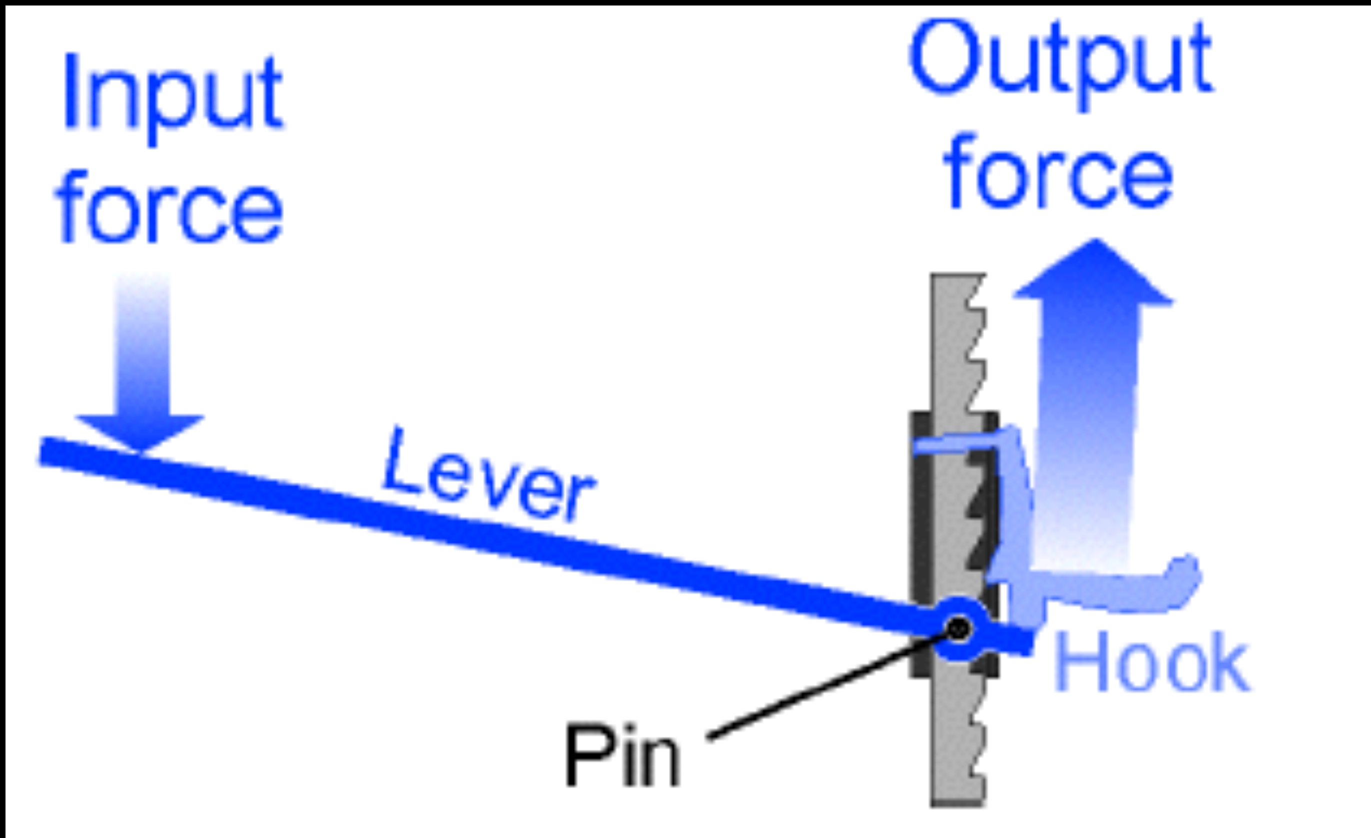


MACHINES

- 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
- At absolute best
  - $W_{in} = W_{out}$
  - $(F\,d)_{in} = (F\,d)_{out}$

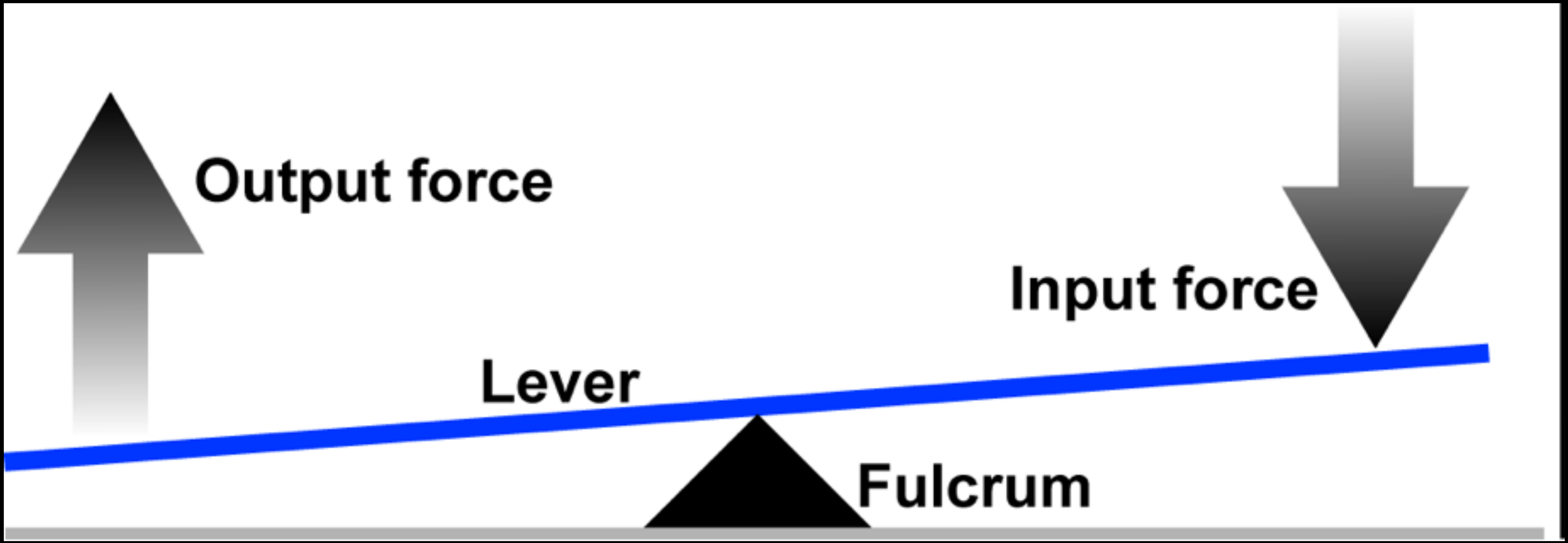
MECHANICAL ADVANTAGE

- Mechanical advantage is the ratio of output force to input force.
- $MA = F_{out}/F_{in}$
- 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.

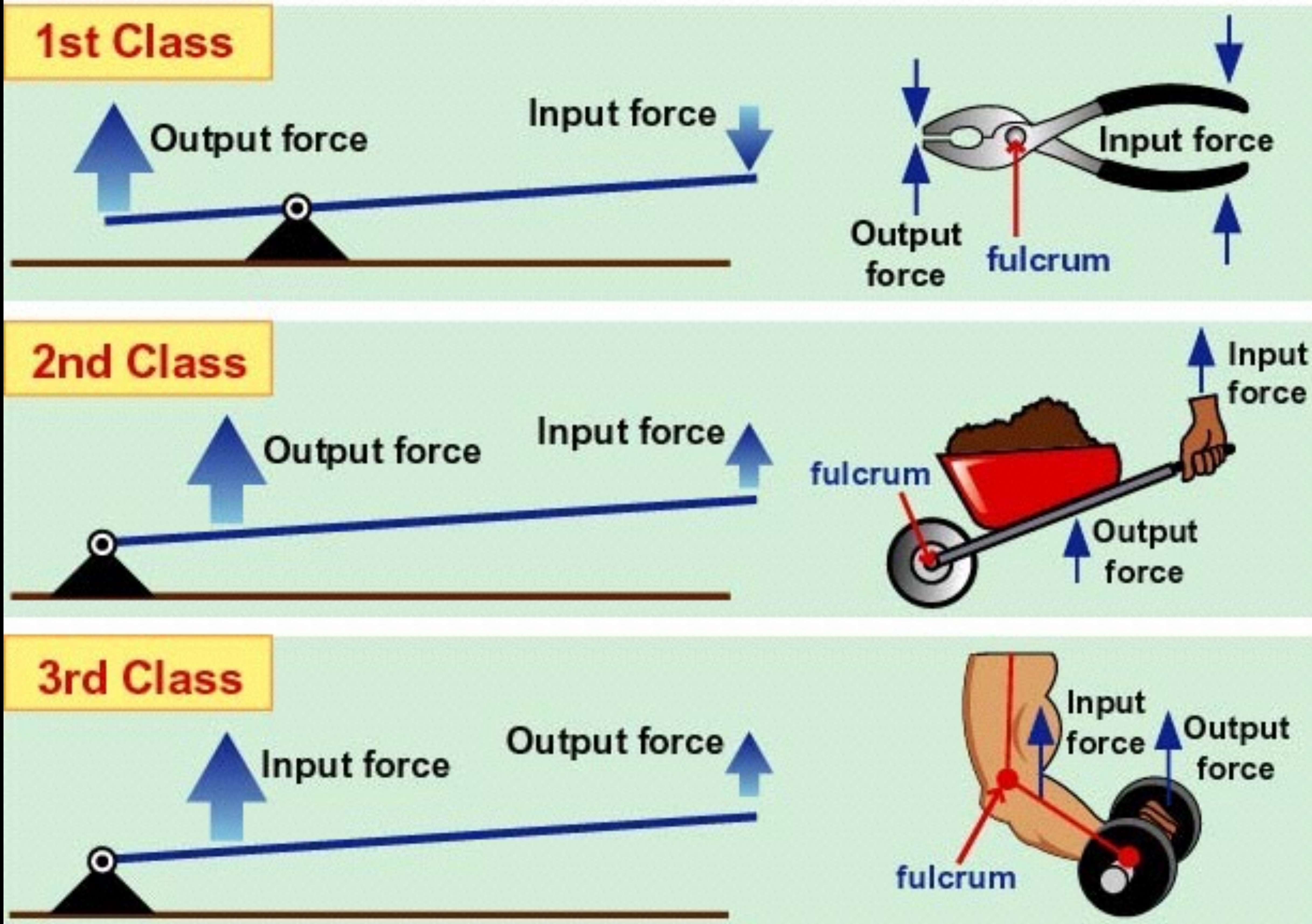


LEVER

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

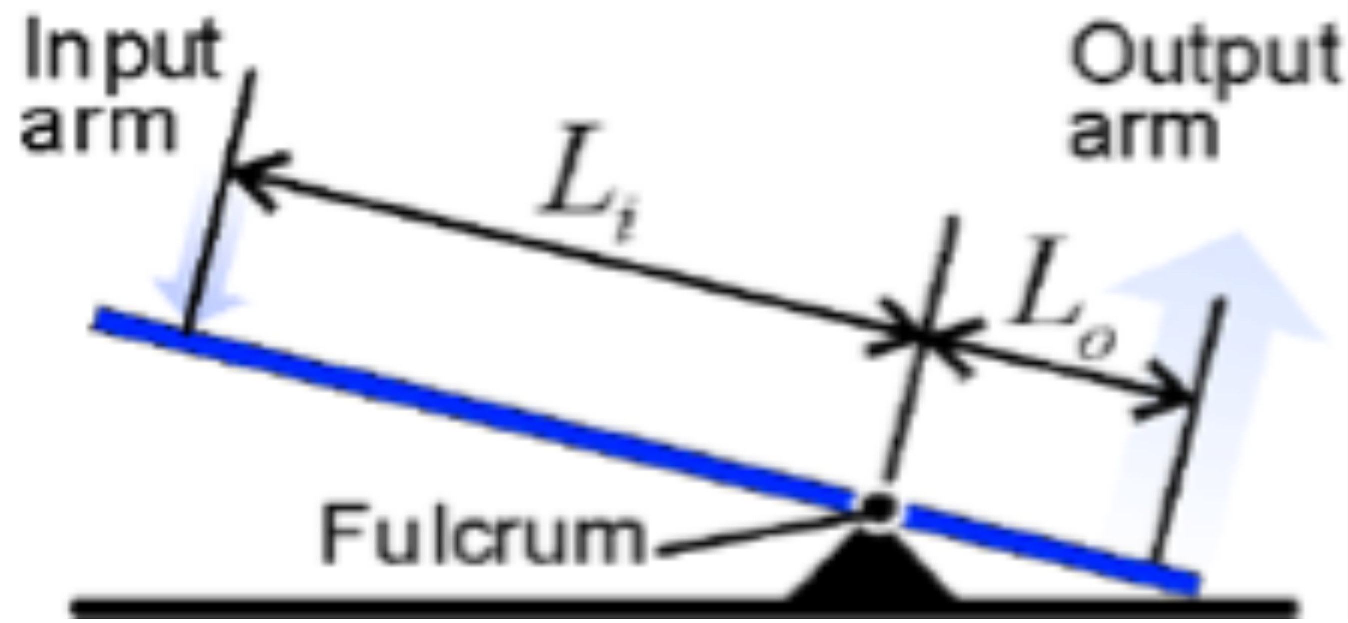


The 3 Classes of Levers



MECHANICAL ADVANTAGE: LEVER

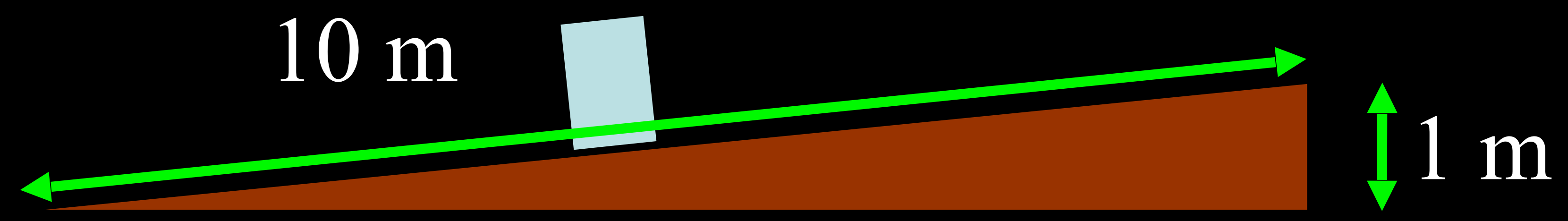
- $MA_{lever} = L_{in}/L_{out}$
- What force must be applied to the end of a 2.0 m long crowbar in order to lift a 500 N rock if the fulcrum of the bar is 0.5 m from the rock?
  - *Ans.* $F_{in} = 125\ N$



RAMP

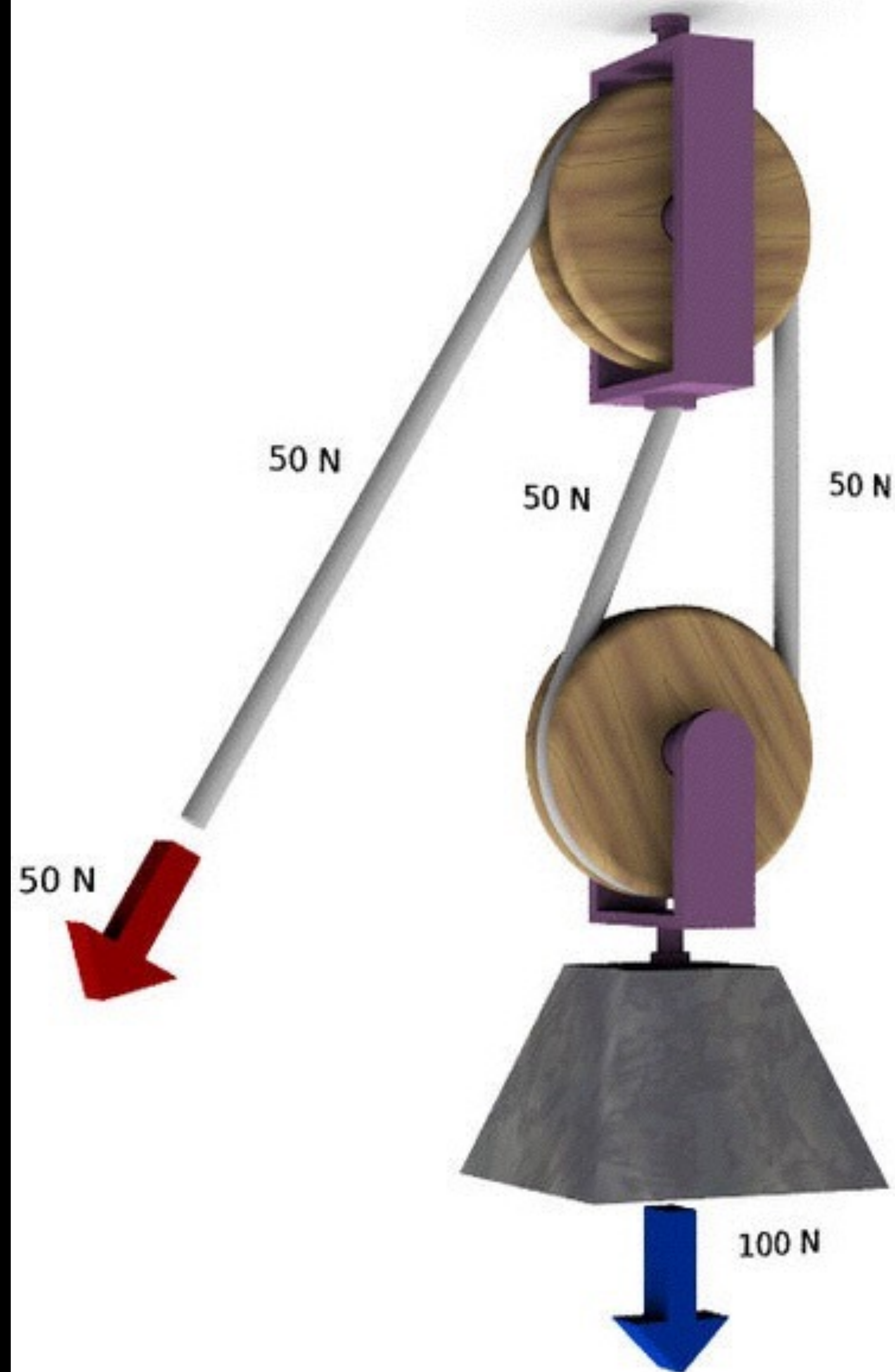
- You need to get a 100 kg couch into a moving van 1.0 m above the ground
- How much work would you need to do to lift it in? How much force would you need to apply?
  - *Ans.* $W = 981\ J$; $F_A = 981\ N$
- Instead you use a ramp 10 m long and 1 m high
- How much work would you need to do to lift it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

(excludes frictional losses)

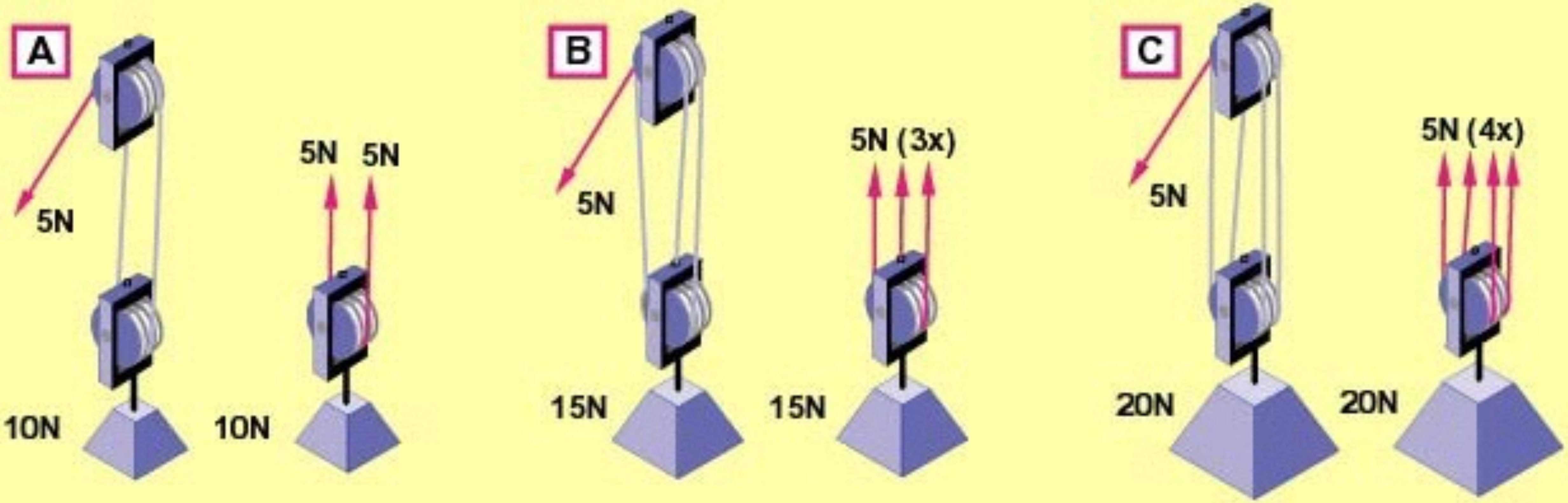


PULLEYS

- 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

EXAMPLE 20

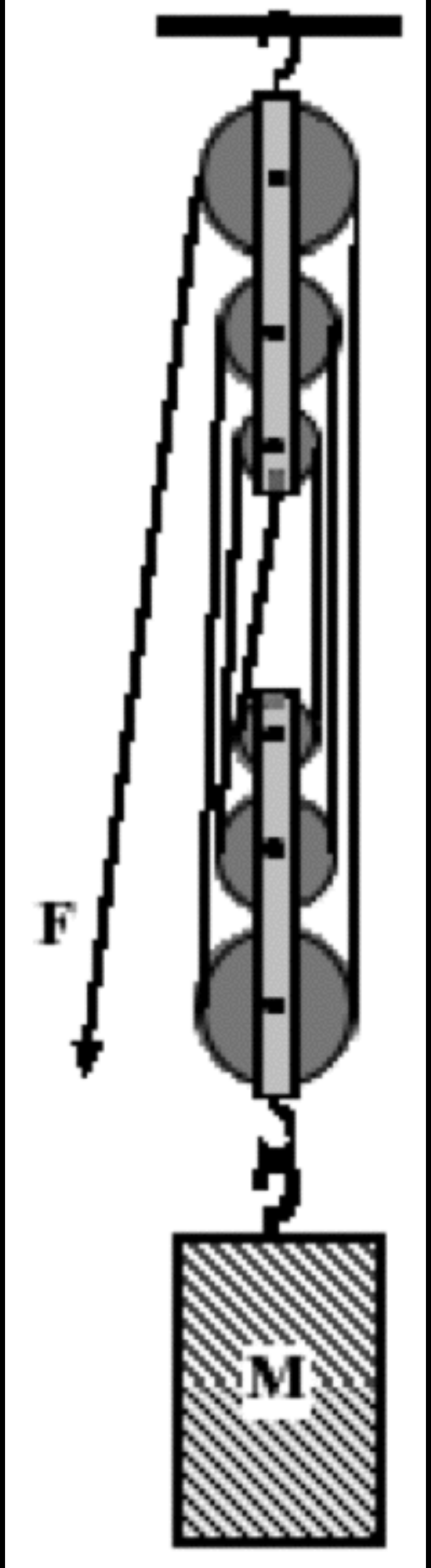
- A pulley system consisting of six pulleys as shown to the right has an input force of 220 N applied to it. As a result of this input force the mass M is lifted a distance of 25.0 cm.

a. How much work was done on the mass M?

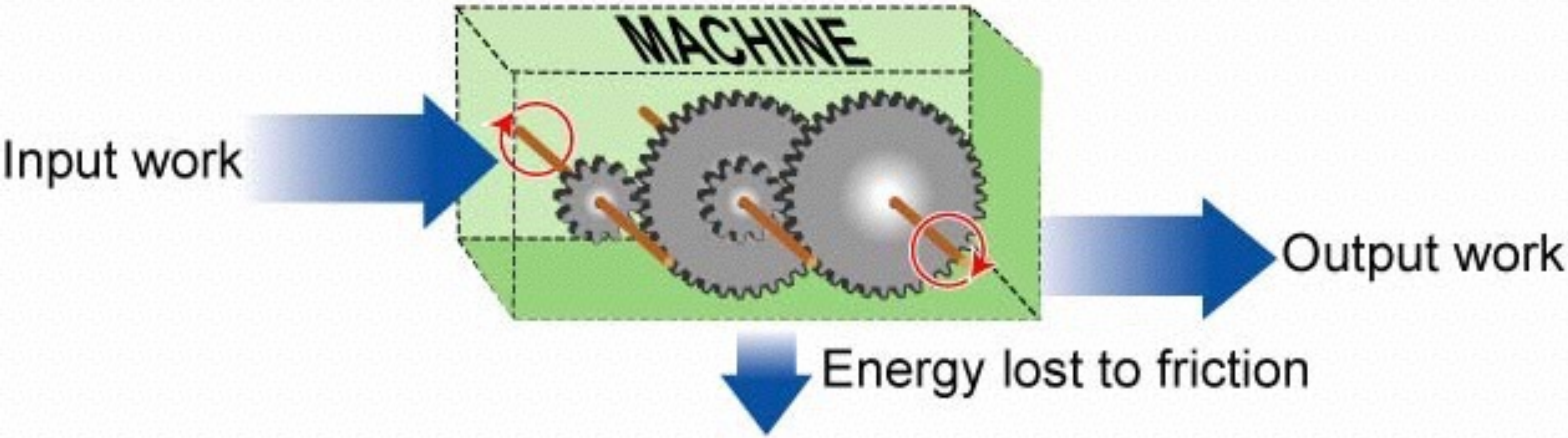
b. Through what distance was the input force applied (how much rope is pulled out)?

   a. *Ans. W = 330 J*

   b. *Ans.* $d_{in} = 1.5\ m$



Efficiency



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

EXAMPLE 21

- 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. 2.03 GW*

EXAMPLE 21B

- The electrical power output of the power plant is 800 MW
- What's the efficiency of the plant?
    - *Ans. e = 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