



Work and Energy

1) To Work or Not to Work

Is it possible to do work on an object that remains at rest?

1) yes

2) no

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Is it possible to do work on an object that remains at rest?

1) yes

2) no

Work requires that a **force acts over a distance**.

If an object does not move at all, there is **no displacement**, and therefore **no work done**.

2) Friction and Work I

A box is being pulled across a rough floor at a constant speed.

What can you say about the work done by friction?

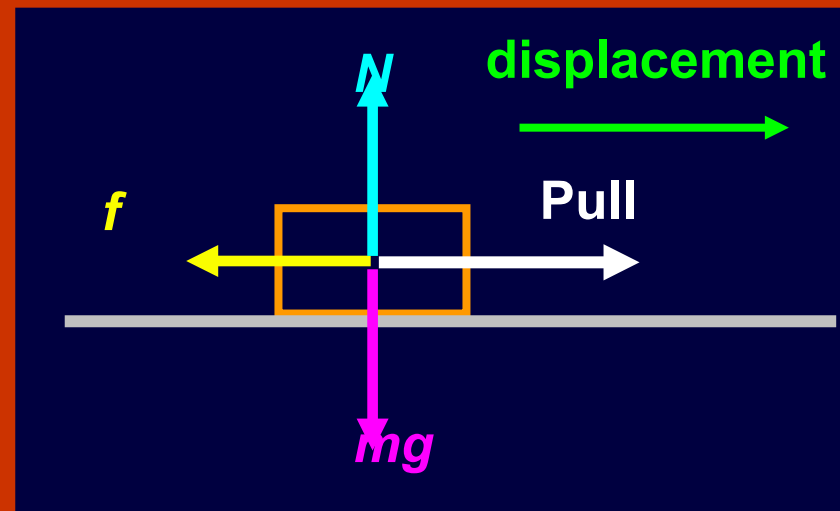
- 1) friction does no work at all
- 2) friction does negative work
- 3) friction does positive work

2) Friction and Work I

A box is being pulled across a rough floor at a constant speed. What can you say about the work done by friction?

- 1) friction does no work at all
- 2) friction does negative work
- 3) friction does positive work

Friction acts in the **opposite** direction to the displacement, so the work is **negative**. Or using the definition of work: $W = Fd \cos \theta$ since $\theta = 180^\circ$, then $W < 0$.



3) Friction and Work II

Can friction ever
do positive work?

1) yes

2) no

3) Friction and Work II

Can friction ever
do positive work?

1) yes

2) no

Consider the case of a box on the back of a pickup truck.
If the box **moves along with the truck**, then it is actually
the **force of friction that is making the box move**.

4) Play Ball!

In a baseball game, the catcher stops a 90-mph pitch. What can you say about the work done by the catcher on the ball?

- 1) catcher has done positive work
- 2) catcher has done negative work
- 3) catcher has done zero work

4) Play Ball!

In a baseball game, the catcher stops a 90-mph pitch. What can you say about the work done by the catcher on the ball?

- 1) catcher has done positive work
- 2) catcher has done negative work
- 3) catcher has done zero work

The force exerted by the catcher is **opposite in direction to the displacement of the ball, so the work is negative.** Or using the definition of work ($W = F d \cos \theta$), since $\theta = 180^\circ$, then $W < 0$. Note that because the work done on the ball is negative, its speed decreases.

Follow-up: What about the work done by the ball on the catcher?

5) Tension and Work

A ball tied to a string is being whirled around in a circle. What can you say about the work done by tension?

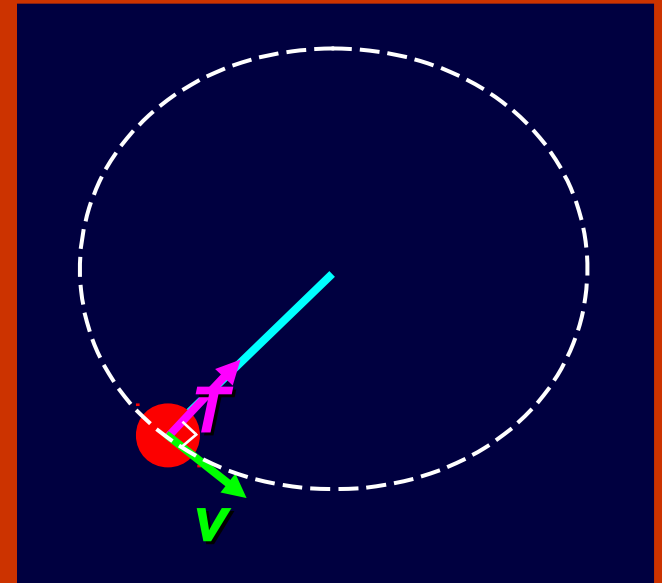
- 1) tension does no work at all
- 2) tension does negative work
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5) Tension and Work

A ball tied to a string is being whirled around in a circle. What can you say about the work done by tension?

- 1) tension does no work at all
- 2) tension does negative work
- 3) tension does positive work

No work is done because the force acts in a **perpendicular** direction to the displacement. Or using the definition of work: $W = Fd \cos \theta$
since $\theta = 90^\circ$, then $W = 0$.

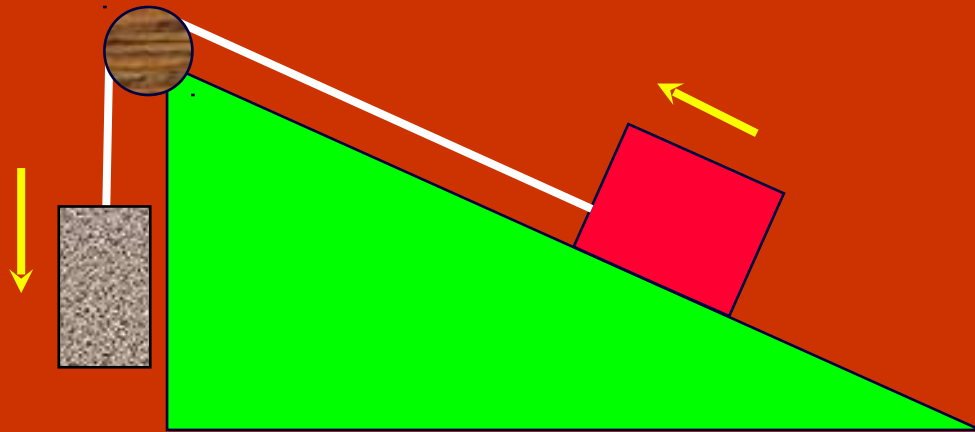


Follow-up: Is there a force in the direction of the velocity?

6) Force and Work

A box is being pulled up a rough incline by a rope connected to a pulley. How many forces are doing work on the box?

- 1) one force
- 2) two forces
- 3) three forces
- 4) four forces
- 5) no forces are doing work



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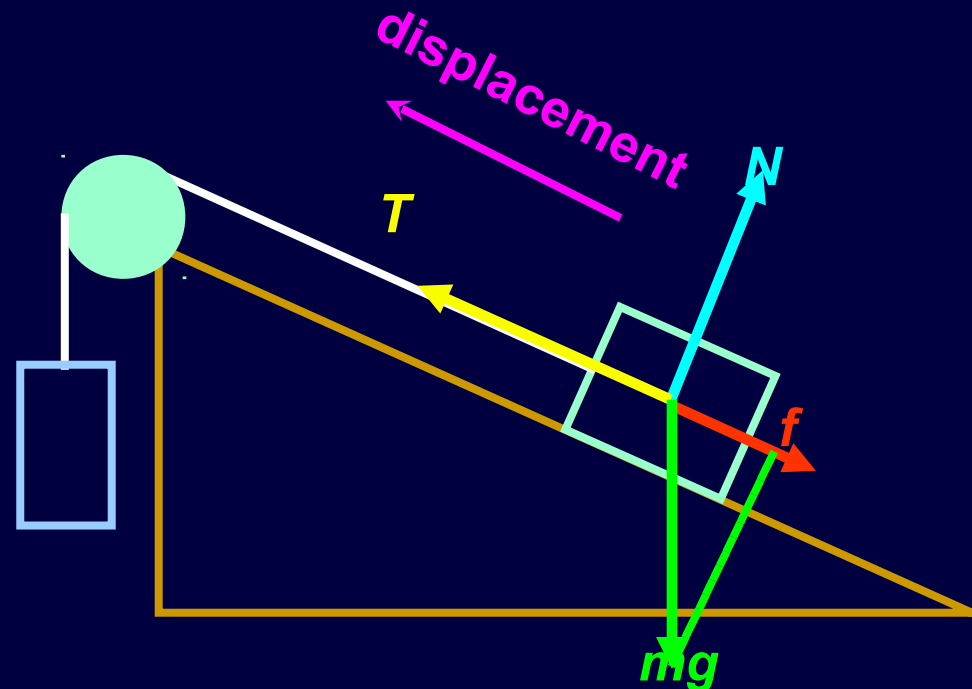
Any force not perpendicular to the motion will do work:

N does **no work**

T does **positive work**

f does **negative work**

mg does **negative work**



7) Kinetic Energy I

By what factor does the kinetic energy of a car change when its speed is tripled?

- 1) no change at all
- 2) factor of 3
- 3) factor of 6
- 4) factor of 9
- 5) factor of 12

7) Kinetic Energy I

By what factor does the kinetic energy of a car change when its speed is tripled?

- 1) no change at all
- 2) factor of 3
- 3) factor of 6
- 4) factor of 9
- 5) factor of 12

Since the kinetic energy is $\frac{1}{2}mv^2$, if the speed increases by a factor of 3, then the KE will increase by a factor of 9.

Follow-up: How would you achieve a KE increase of a factor of 2?

8) Kinetic Energy II

Car #1 has twice the mass of car #2, but they both have the same kinetic energy. How do their speeds compare?

1) $2 v_1 = v_2$

2) $\sqrt{2} v_1 = v_2$

3) $4 v_1 = v_2$

4) $v_1 = v_2$

5) $8 v_1 = v_2$

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4) $v_1 = v_2$

5) $8 v_1 = v_2$

Since the kinetic energy is $\frac{1}{2} m v^2$, and the mass of car #1 is greater, then car #2 must be moving faster. If the ratio of m_1/m_2 is 2, then the ratio of v^2 values must also be 2. This means that the ratio of v_2/v_1 must be the square root of 2.

9) Free Fall I

Two stones, one twice the mass of the other, are dropped from a cliff. Just before hitting the ground, what is the kinetic energy of the heavy stone compared to the light one?

- 1) quarter as much
- 2) half as much
- 3) the same
- 4) twice as much
- 5) four times as much

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- 2) half as much
- 3) the same
- 4) twice as much
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Consider the work done by gravity to make the stone fall distance d :

$$\Delta KE = W_{\text{net}} = F d \cos\theta$$

$$\Delta KE = mg d$$

Thus, the stone with the **greater mass** has the **greater KE**, which is **twice** as big for the heavy stone.

Follow-up: How do the initial values of gravitational PE compare?

10) Free Fall II

In the previous question, just before hitting the ground, what is the final speed of the heavy stone compared to the light one?

- 1) quarter as much
- 2) half as much
- 3) the same
- 4) twice as much
- 5) four times as much

10) Free Fall II

In the previous question, just before hitting the ground, what is the final speed of the heavy stone compared to the light one?

- 1) quarter as much
- 2) half as much
- 3) the same
- 4) twice as much
- 5) four times as much

All freely falling objects fall at the same rate, which is g . Since the acceleration is the same for both, and the distance is the same, then the final speeds will be the same for both stones.

11) Work and KE

A child on a skateboard is moving at a speed of 2 m/s. After a force acts on the child, her speed is 3 m/s. What can you say about the work done by the external force on the child?

- 1) positive work was done
- 2) negative work was done
- 3) zero work was done

11) Work and KE

A child on a skateboard is moving at a speed of 2 m/s. After a force acts on the child, her speed is 3 m/s. What can you say about the work done by the external force on the child?

- 1) positive work was done
- 2) negative work was done
- 3) zero work was done

The kinetic energy of the child increased because her speed increased. This increase in KE was the result of positive work being done. Or, from the definition of work, since $W = \Delta KE = KE_f - KE_i$ and we know that $KE_f > KE_i$ in this case, then the work W must be positive.

Follow-up: What does it mean for negative work to be done on the child?

12) Slowing Down

If a car traveling **60 km/hr** can brake to a stop within **20 m**, what is its stopping distance if it is traveling **120 km/hr**? Assume that the braking force is the same in both cases.

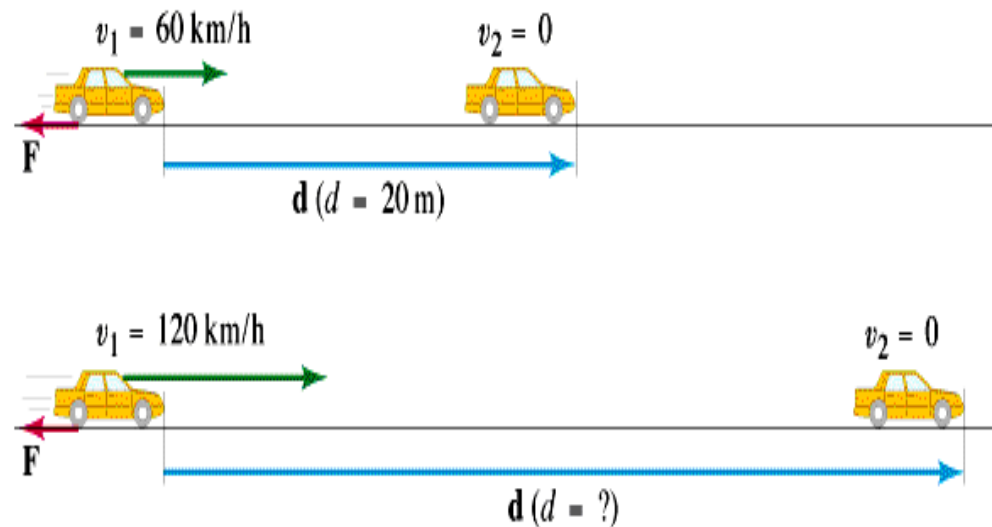
1) 20 m

2) 30 m

3) 40 m

4) 60 m

5) 80 m



12) Slowing Down

If a car traveling **60 km/hr** can brake to a stop within **20 m**, what is its stopping distance if it is traveling **120 km/hr**? Assume that the braking force is the same in both cases.

1) 20 m

2) 30 m

3) 40 m

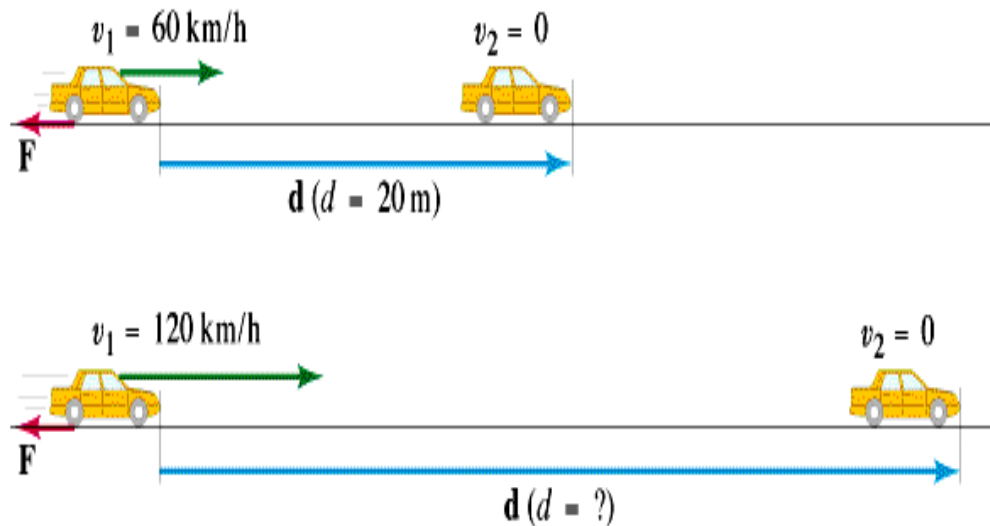
4) 60 m

5) 80 m

$$Fd = W_{\text{net}} = \Delta KE = 0 - 1/2 mv^2$$

$$\text{thus: } |F|d = 1/2 mv^2$$

Therefore, if the speed **doubles**, the stopping distance gets **four times larger**.



13) Speeding Up I

A car starts from rest and accelerates to 30 mph. Later, it gets on a highway and accelerates to 60 mph. Which takes more energy, the 0→30 mph, or the 30→60 mph?

- 1) 0 → 30 mph
- 2) 30 → 60 mph
- 3) both the same

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1) 0 → 30 mph

2) 30 → 60 mph

3) both the same

The change in KE ($\frac{1}{2}mv^2$) involves the *velocity squared*.

So in the first case, we have: $\frac{1}{2}m(30^2 - 0^2) = \frac{1}{2}m(900)$

In the second case, we have: $\frac{1}{2}m(60^2 - 30^2) = \frac{1}{2}m(2700)$

Thus, the *bigger energy change occurs in the second case*.

Follow-up: How much energy is required to stop the 60-mph car?

14) Speeding Up II

The work W_0 accelerates a car from 0 to 50 km/hr. How much work is needed to accelerate the car from 50 km/hr to 150 km/hr?

- 1) $2 W_0$
- 2) $3 W_0$
- 3) $6 W_0$
- 4) $8 W_0$
- 5) $9 W_0$

14) Speeding Up II

The work W_0 accelerates a car from 0 to 50 km/hr. How much work is needed to accelerate the car from 50 km/hr to 150 km/hr?

1) $2 W_0$

2) $3 W_0$

3) $6 W_0$

4) $8 W_0$

5) $9 W_0$

Let's call the two speeds v and $3v$, for simplicity.

We know that the work is given by: $W = \Delta KE = KE_f - KE_i$

Case #1: $W_0 = 1/2 m (v^2 - 0^2) = 1/2 m (v^2)$

Case #2: $W = 1/2 m (3v)^2 - v^2 = 1/2 m (9v^2 - v^2) = 1/2 m (8v^2) = 8 W_0$

Follow-up: How much work is required to stop the 150-km/hr car?

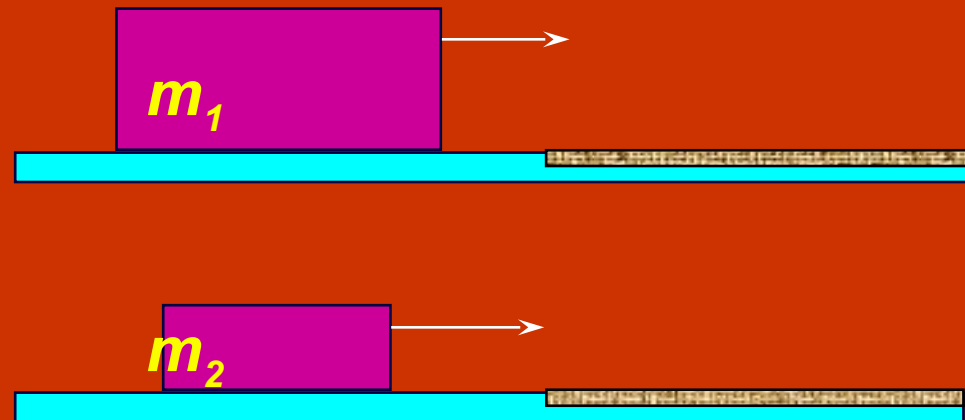
15) Work and Energy I

Two blocks of mass m_1 and m_2 ($m_1 > m_2$) slide on a frictionless floor and have the **same kinetic energy** when they hit a long rough stretch ($\mu > 0$), which slows them down to a stop. **Which one goes farther?**

1) m_1

2) m_2

3) they will go the same distance



15) Work and Energy I

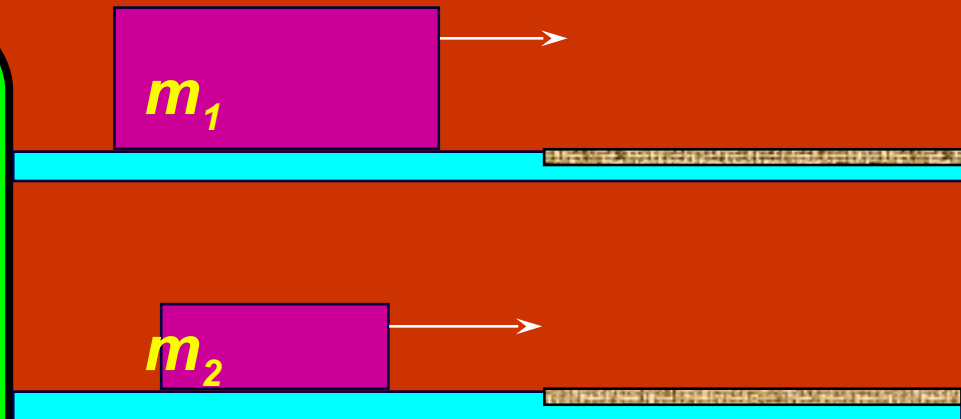
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1) m_1

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3) they will go the same distance

With the **same ΔKE** , both blocks must have the **same work** done to them by friction. The friction force is **less** for m_2 , so stopping **distance** must be **greater**.



Follow-up: Which block has the greater magnitude of acceleration?

16) Work and Energy II

A golfer making a putt gives the ball an initial velocity of v_0 , but he has badly misjudged the putt, and the ball only travels one-quarter of the distance to the hole. If the resistance force due to the grass is constant, what speed should he have given the ball (from its original position) in order to make it into the hole?

1) $2 v_0$

2) $3 v_0$

3) $4 v_0$

4) $8 v_0$

5) $16 v_0$

16) Work and Energy II

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1) $2 v_0$

2) $3 v_0$

3) $4 v_0$

4) $8 v_0$

5) $16 v_0$

In traveling **4 times the distance**, the resistive force will do **4 times the work**. Thus, the ball's **initial KE must be 4 times greater** in order to just reach the hole — this requires an **increase in the initial speed by a factor of 2**, since **$KE = 1/2 mv^2$** .

17) Sign of the Energy I

**Is it possible for the
kinetic energy of an
object to be negative?**

1) yes

2) no

17) Sign of the Energy I

Is it possible for the kinetic energy of an object to be negative?

1) yes

2) no

The kinetic energy is $\frac{1}{2}mv^2$. The mass and the velocity squared will always be positive, so KE must always be positive.

18) Sign of the Energy II

Is it possible for the
gravitational potential
energy of an object to
be negative?

1) yes

2) no

18) Sign of the Energy II

Is it possible for the gravitational potential energy of an object to be negative?

1) yes

2) no

Gravitational PE is mgh , where height h is measured relative to some arbitrary reference level where $PE = 0$. For example, a book on a table has positive PE if the zero reference level is chosen to be the floor. However, if the **ceiling is the zero level**, then the **book has negative PE on the table**. It is only differences (or changes) in PE that have any physical meaning.

19) KE and PE

You and your friend both solve a problem involving a skier going down a slope, starting from rest. The two of you have chosen **different levels for $y = 0$** in this problem. **Which of the following quantities will you and your friend agree on?**

- 1) only B
- 2) only C
- 3) A, B, and C
- 4) only A and C
- 5) only B and C

A) skier's PE

B) skier's change in PE

C) skier's final KE

19) KE and PE

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- 4) only A and C
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A) skier's PE

B) skier's change in PE

C) skier's final KE

The **gravitational PE depends upon the reference level**, but the **difference ΔPE does not!** The work done by gravity must be the same in the two solutions, so **ΔPE and ΔKE should be the same.**

Follow-up: Does anything change *physically* by the choice of $y = 0$?

20) Up the Hill

Two paths lead to the top of a big hill. One is steep and direct, while the other is twice as long but less steep. How much more potential energy would you gain if you take the longer path?

- 1) the same
- 2) twice as much
- 3) four times as much
- 4) half as much
- 5) you gain no PE in either case

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Since your vertical position (height) changes by the same amount in each case, the gain in potential energy is the same.

Follow-up: How much more work do you do in taking the steeper path?

Follow-up: Which path would you rather take? Why?

21) Elastic Potential Energy

How does the work required to stretch a spring 2 cm compare with the work required to stretch it 1 cm?

- 1) same amount of work
- 2) twice the work
- 3) 4 times the work
- 4) 8 times the work

21) Elastic Potential Energy

How does the work required to stretch a spring 2 cm compare with the work required to stretch it 1 cm?

- 1) same amount of work
- 2) twice the work
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- 4) 8 times the work

The elastic potential energy is $\frac{1}{2} kx^2$. So in the second case, the **elastic PE is 4 times greater** than in the first case. Thus, the **work required to stretch the spring is also 4 times greater.**

22) Springs and Gravity

A mass attached to a vertical spring causes the spring to stretch and the mass to move downwards. What can you say about the spring's potential energy (PE_s) and the gravitational potential energy (PE_g) of the mass?

- 1) both PE_s and PE_g decrease
- 2) PE_s increases and PE_g decreases
- 3) both PE_s and PE_g increase
- 4) PE_s decreases and PE_g increases
- 5) PE_s increases and PE_g is constant

22) Springs and Gravity

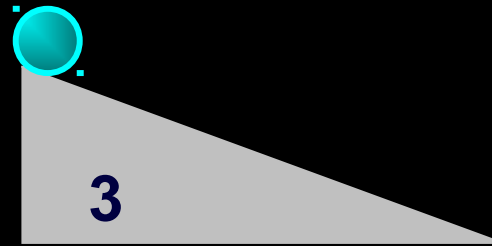
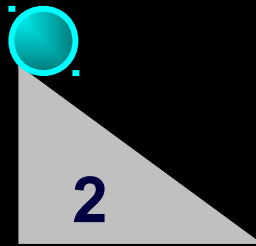
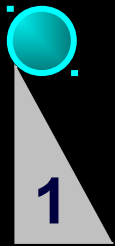
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- 2) PE_s increases and PE_g decreases
- 3) both PE_s and PE_g increase
- 4) PE_s decreases and PE_g increases
- 5) PE_s increases and PE_g is constant

The spring is **stretched**, so its **elastic PE increases**, since $PE_s = 1/2 kx^2$. The mass moves down to a **lower position**, so its **gravitational PE decreases**, since $PE_g = mgh$.

23) Down the Hill

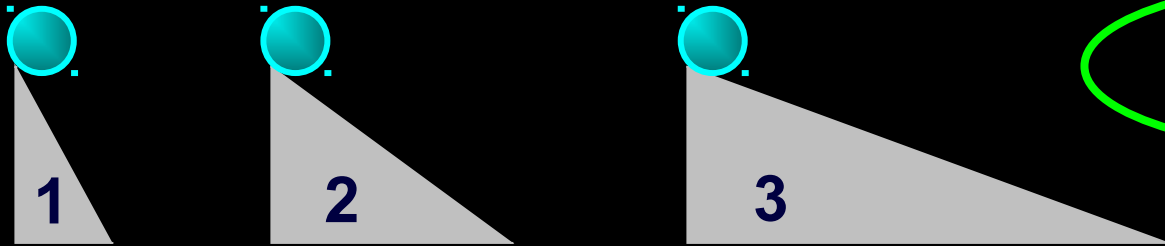
Three balls of equal mass start from rest and roll down different ramps. All ramps have the same height. Which ball has the greater speed at the bottom of its ramp?



4) same speed
for all balls

23) Down the Hill

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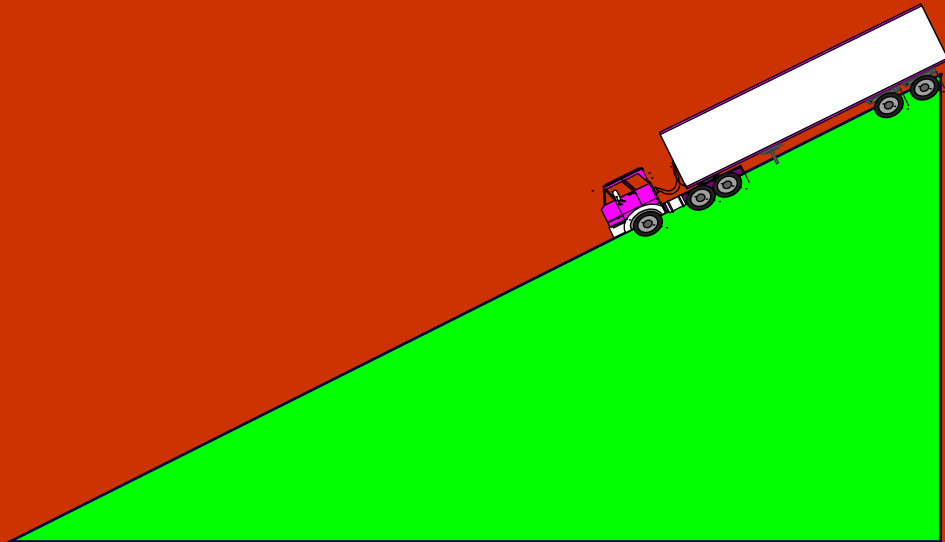
All of the balls have the **same initial gravitational PE**, since they are all at the **same height** ($PE = mgh$). Thus, when they get to the bottom, they all have the **same final KE**, and hence the **same speed** ($KE = 1/2 mv^2$).

Follow-up: Which ball takes longer to get down the ramp?

24) Runaway Truck

A truck, initially at rest, rolls down a frictionless hill and attains a speed of **20 m/s** at the bottom. To achieve a speed of **40 m/s** at the bottom, how many times higher must the hill be?

- 1) half the height
- 2) the same height
- 3) $\sqrt{2}$ times the height
- 4) twice the height
- 5) four times the height



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Use energy conservation:

▶ initial energy: $E_i = PE_g = mgH$

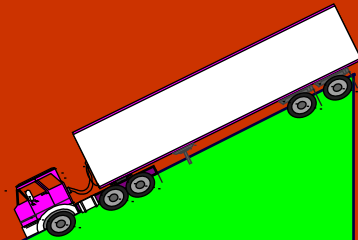
▶ final energy: $E_f = KE = 1/2 mv^2$

Conservation of Energy:

$$E_i = mgH = E_f = 1/2 mv^2$$

therefore: $gH = 1/2 v^2$

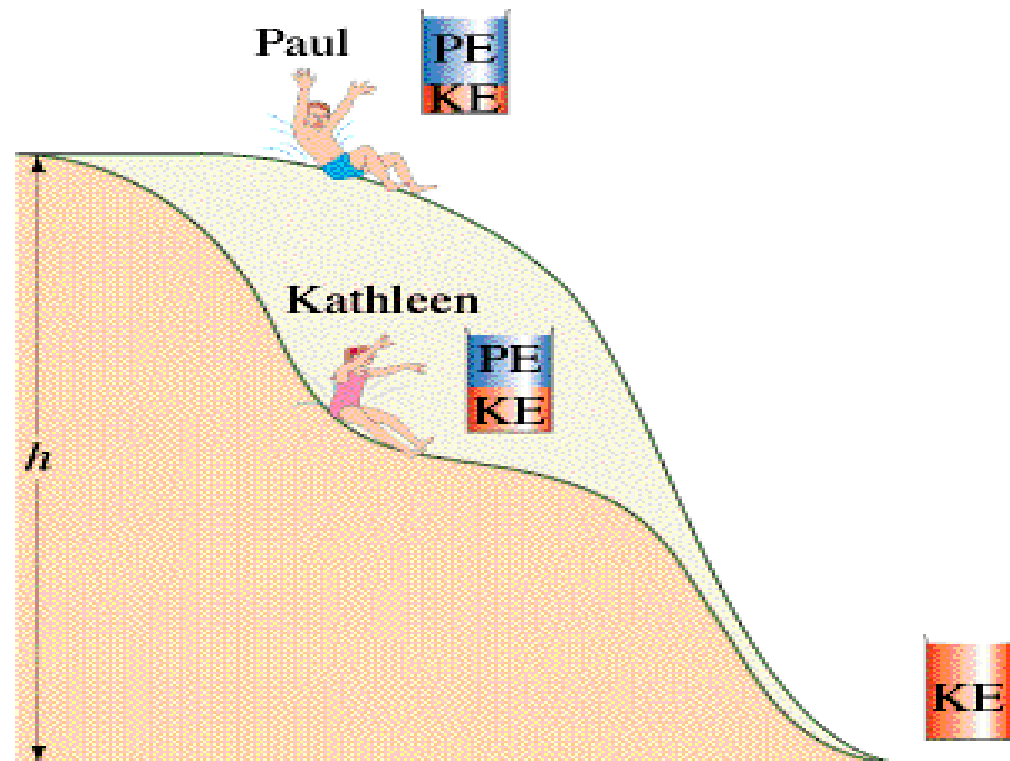
So if v doubles, H quadruples!



25) Water Slide

Paul and Kathleen start from rest at the same time on frictionless water slides with different shapes. Who makes it to the bottom first?

- 1) Paul
- 2) Kathleen
- 3) both the same



25) Water Slide

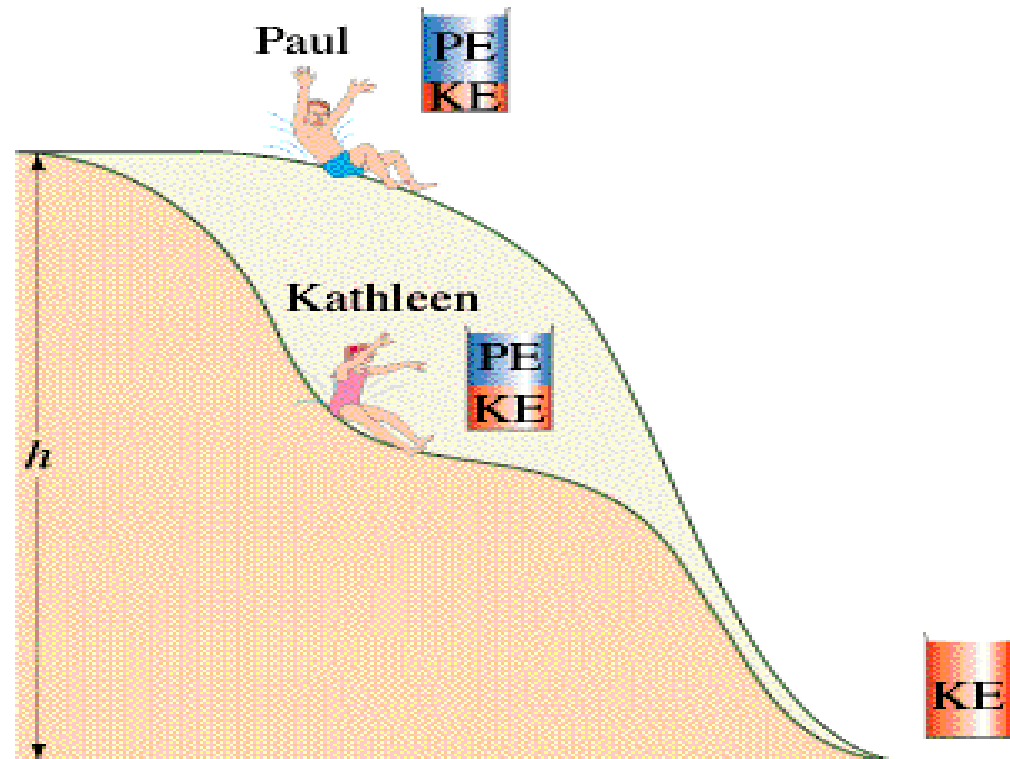
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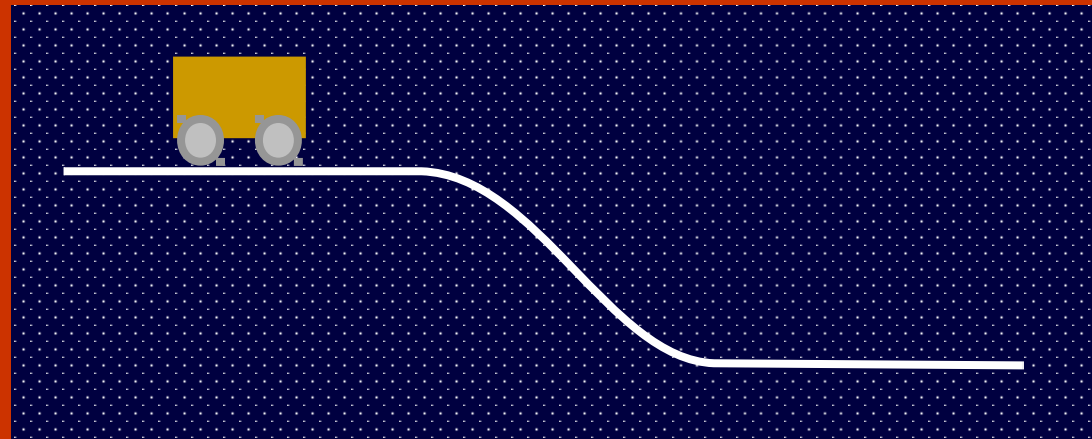
Even though they both have the same *final velocity*, Kathleen is at a lower height than Paul for most of her ride. Thus she always has a *larger velocity* during her ride and therefore arrives earlier!



26) Cart on a Hill

A cart starting from rest rolls down a hill and at the bottom has a speed of **4 m/s**. If the cart were given an initial push, so its initial speed at the top of the hill was **3 m/s**, what would be its speed at the bottom?

- 1) 4 m/s
- 2) 5 m/s
- 3) 6 m/s
- 4) 7 m/s
- 5) 25 m/s



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2) 5 m/s

3) 6 m/s

4) 7 m/s

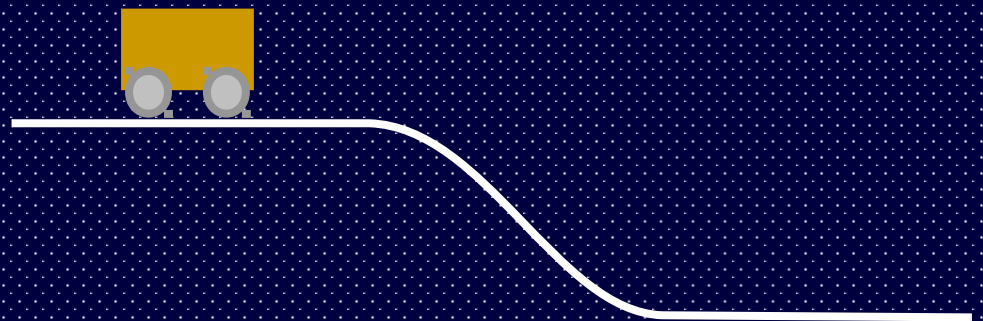
5) 25 m/s

When starting from rest, the cart's PE is changed into KE:

$$\Delta PE = \Delta KE = 1/2 m(4)^2$$

When starting from 3 m/s, the final KE is:

$$\begin{aligned} KE_f &= KE_i + \Delta KE \\ &= 1/2 m(3)^2 + 1/2 m(4)^2 \\ &= 1/2 m(25) \\ &= 1/2 m(5)^2 \end{aligned}$$



Speed is not the same as kinetic energy

27) Falling Leaves

You see a leaf falling to the ground with **constant speed**. When you first notice it, the leaf has initial total energy $PE_i + KE_i$. You watch the leaf until just before it hits the ground, at which point it has final total energy $PE_f + KE_f$. How do these total energies compare?

1) $PE_i + KE_i > PE_f + KE_f$

2) $PE_i + KE_i = PE_f + KE_f$

3) $PE_i + KE_i < PE_f + KE_f$

4) impossible to tell from the information provided

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3) $PE_i + KE_i < PE_f + KE_f$

4) impossible to tell from the information provided

As the leaf falls, **air resistance exerts a force on it opposite to its direction of motion**. This force does **negative work**, which prevents the leaf from accelerating. This frictional force is a non-conservative force, so the **leaf loses energy as it falls**, and its **final total energy is less than its initial total energy**.

Follow-up: What happens to leaf's KE as it falls? What is net work done?

28) Falling Balls

You throw a ball straight up into the air.

In addition to *gravity*, the ball feels a force due to *air resistance*. Compared to the time it takes the ball to go up, the time it takes to come back down is:

- 1) smaller
- 2) the same
- 3) greater

28) Falling Balls

You throw a ball straight up into the air.

In addition to *gravity*, the ball feels a force due to *air resistance*. Compared to the time it takes the ball to go up, the time it takes to come back down is:

- 1) smaller
- 2) the same
- 3) greater

Due to air friction, the ball is **continuously losing mechanical energy**. Therefore it has **less KE** (and consequently a **lower speed**) on the way down. **This means it will take more time on the way down !!**

Follow-up: How does the force of air resistance compare to gravity when the ball reaches terminal velocity?

29) Power

Engine #1 produces twice the power of engine #2. Can we conclude that engine #1 does twice as much work as engine #2?

1) yes

2) no

29) Power

Engine #1 produces twice the power of engine #2. Can we conclude that engine #1 does twice as much work as engine #2?

1) yes

2) no

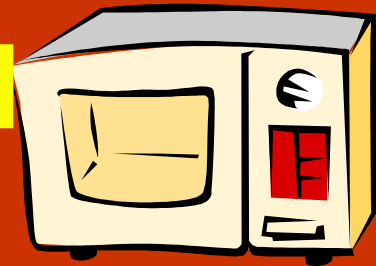
No!! We cannot conclude anything about how much work each engine does. Given the power output, the work will depend upon how much time is used. For example, engine #1 may do the same amount of work as engine #2, but in half the time.

30) Energy Consumption

Which contributes more to the cost of your electric bill each month, a 1500-Watt hair dryer or a 600-Watt microwave oven?

- 1) hair dryer
- 2) microwave oven
- 3) both contribute equally
- 4) depends upon what you cook in the oven
- 5) depends upon how long each one is on

600 W



1500 W



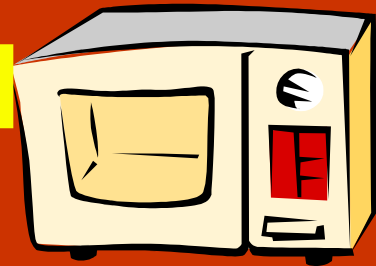
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- (3) both contribute equally
- (4) depends upon what you cook in the oven
- (5) depends upon how long each one is on

We already saw that what you actually pay for is *energy*. To find the energy consumption of an appliance, you must know more than just the power rating — **you have to know how long it was running.**

600 W



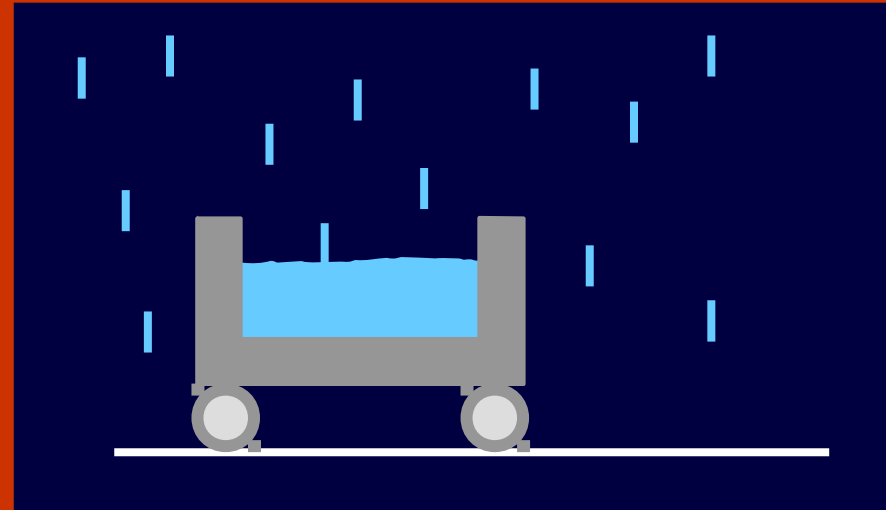
1500 W



31) Rolling in the Rain

An open cart rolls along a frictionless track while it is raining. As it rolls, what happens to the speed of the cart as the rain collects in it? (assume that the rain falls vertically into the box)

- 1) speeds up
- 2) maintains constant speed
- 3) slows down
- 4) stops immediately



31) Rolling in the Rain

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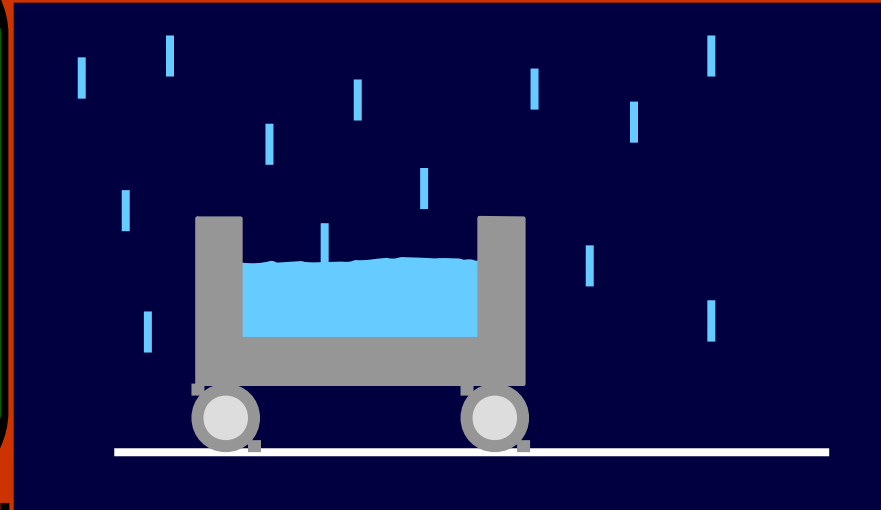
1) speeds up

2) maintains constant speed

3) slows down

4) stops immediately

Since the rain falls in vertically, it adds no momentum to the box, thus the box's momentum is conserved. However, since the mass of the box slowly *increases* with the added rain, its velocity has to *decrease*.



Follow-up: What happens to the cart when it stops raining?

32) Momentum and KE I

A system of particles is known to have a total kinetic energy of zero. What can you say about the total momentum of the system?

- 1) momentum of the system is positive
- 2) momentum of the system is negative
- 3) momentum of the system is zero
- 4) you cannot say anything about the momentum of the system

32) Momentum and KE I

A system of particles is known to have a total kinetic energy of zero. What can you say about the total momentum of the system?

- 1) momentum of the system is positive
- 2) momentum of the system is negative
- 3) momentum of the system is zero
- 4) you cannot say anything about the momentum of the system

Since the total kinetic energy is zero, this means that all of the particles are at rest ($v = 0$). Therefore, since nothing is moving, the total momentum of the system must also be zero.

33) Momentum and KE II

A system of particles is known to have a total momentum of zero.

Does it necessarily follow that the total kinetic energy of the system is also zero?

1) yes

2) no

33) Momentum and KE II

A system of particles is known to have a total momentum of zero.

Does it necessarily follow that the total kinetic energy of the system is also zero?

1) yes

2) no

Momentum is a vector, so the fact that $p_{\text{tot}} = 0$ does not mean that the particles are at rest! They could be moving such that their momenta cancel out when you add up all of the vectors. In that case, since they are moving, the particles would have non-zero KE.

34) Momentum and KE III

Two objects are known to have the same momentum. Do these two objects necessarily have the same kinetic energy?

1) yes

2) no

34) Momentum and KE III

Two objects are known to have the same momentum. Do these two objects necessarily have the same kinetic energy?

1) yes

2) no

If object #1 has mass m and speed v , and object #2 has mass $1/2 m$ and speed $2v$, they will both have the same momentum. However, since $KE = 1/2 mv^2$, we see that object #2 has twice the kinetic energy of object #1, due to the fact that the velocity is squared.

35) Collision Course

A **small car** and a **large truck** collide head-on and stick together. Which one has the larger momentum change?

- 1) the car
- 2) the truck
- 3) they both have the same momentum change
- 4) can't tell without knowing the final velocities



35) Collision Course

A **small car** and a **large truck** collide head-on and stick together. Which one has the larger momentum change?

- 1) the car
- 2) the truck
- 3) they both have the same momentum change
- 4) can't tell without knowing the final velocities

Since the total momentum of the system is conserved, that means that $\Delta p = 0$ for the **car and truck combined**. Therefore, Δp_{car} must be **equal and opposite** to that of the truck ($-\Delta p_{\text{truck}}$) in order for the total momentum change to be zero. Note that this conclusion also follows from Newton's 3rd Law.

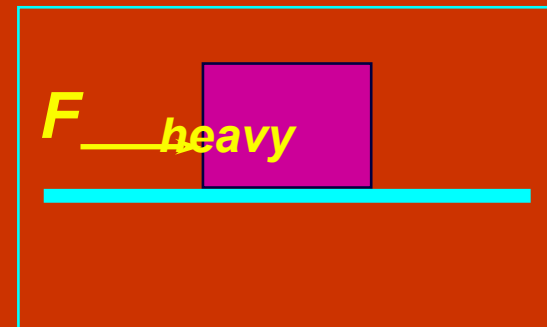
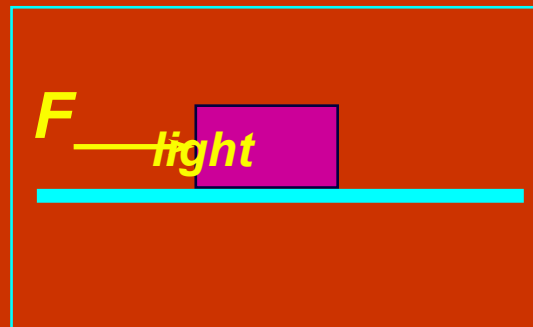


Follow-up: Which one feels the larger acceleration?

36) Two Boxes I

Two boxes, one heavier than the other, are initially at rest on a horizontal frictionless surface. The same constant force F acts on each one for exactly **1 second**. Which box has more momentum after the force acts?

- 1) the heavier one
- 2) the lighter one
- 3) both the same



36) Two Boxes I

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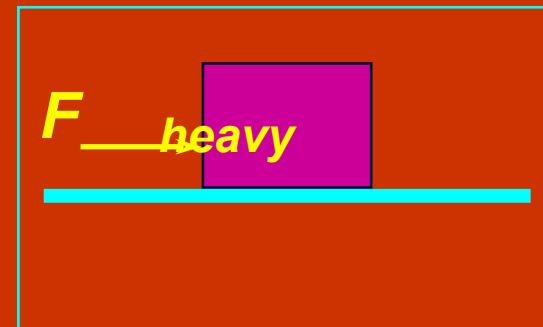
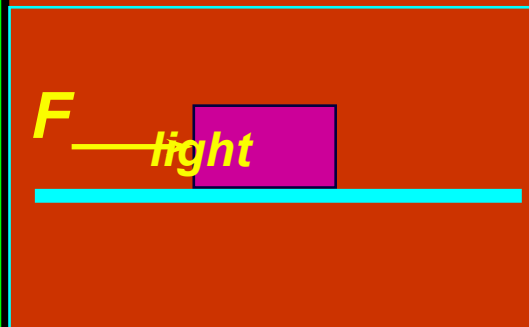
3) both the same

We know:
$$F_{av} = \frac{\Delta p}{\Delta t}$$

so impulse $\Delta p = F_{av} \Delta t$.

In this case F and Δt are the **same** for both boxes !

Both boxes will have the **same final momentum**.



37) Two Boxes II

In the previous question,
which box has the larger
velocity after the force acts?

- 1) the heavier one
- 2) the lighter one
- 3) both the same

37) Two Boxes II

In the previous question, which box has the larger velocity after the force acts?

1) the heavier one

2) the lighter one

3) both the same

The force is related to the acceleration by Newton's 2nd Law ($F = ma$). The lighter box therefore has the greater acceleration, and will reach a higher speed after the 1-second time interval.

Follow-up: Which box has gone a larger distance after the force acts?

Follow-up: Which box has gained more KE after the force acts?

38) Watch Out!

You drive around a curve in a narrow one-way street at **30 mph** when you see an **identical** car heading straight toward you at **30 mph**. You have two options: **hit the car head-on** or **swerve into a massive concrete wall** (also head-on). What should you do?

- 1) hit the other car
- 2) hit the wall
- 3) makes no difference
- 4) call your physics prof!!
- 5) get insurance!

38) Watch Out!

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- 1) hit the other car
- 2) hit the wall
- 3) makes no difference
- 4) call your physics prof!!
- 5) get insurance!

In **both** cases your momentum will decrease to zero in the collision. Given that the **time Δt** of the collision is the same, then the **force exerted on YOU** will be the same!!

If a **truck** is approaching at 30 mph, then you'd be better off **hitting the wall** in that case. On the other hand, if it's only a **mosquito**, well, you'd be better off **running him down**...

39) Impulse

A small beanbag and a bouncy rubber ball are dropped from the same height above the floor.

They both have the same mass.

Which one will impart the greater impulse to the floor when it hits?

- 1) the beanbag
- 2) the rubber ball
- 3) both the same

39) Impulse

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They both have the same mass.

Which one will impart the greater impulse to the floor when it hits?

1) the beanbag

2) the rubber ball

3) both the same

Both objects reach the same speed at the floor. However, while the beanbag comes to rest on the floor, the ball bounces back up with nearly the same speed as it hit. Thus, the **change in momentum for the ball is greater, because of the rebound.**

The impulse delivered by the ball is twice that of the beanbag.

$$\text{For the beanbag: } \Delta p = p_f - p_i = 0 - (-mv) = mv$$

$$\text{For the rubber ball: } \Delta p = p_f - p_i = mv - (-mv) = 2mv$$

Follow-up: Which one imparts the larger force to the

40) Singing in the Rain

A person stands under an umbrella during a rainstorm. Later the rain turns to hail, although the number of “drops” hitting the umbrella per time and their speed remains the same. Which case requires more force to hold the umbrella?

- 1) when it is hailing
- 2) when it is raining
- 3) same in both cases

40) Singing in the Rain

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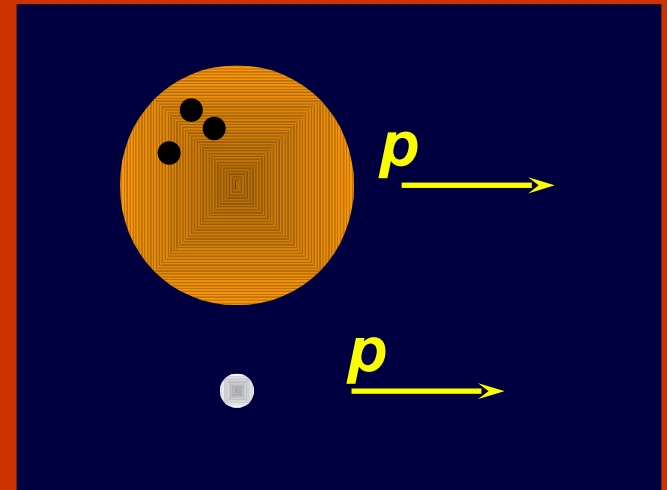
- 1) when it is hailing
- 2) when it is raining
- 3) same in both cases

When the raindrops hit the umbrella, they tend to splatter and run off, whereas the hailstones hit the umbrella and bounce back upwards. Thus, the change in momentum (impulse) is greater for the hail. Since $\Delta p = F \Delta t$, more force is required in the hailstorm. This is similar to the situation with the bouncy rubber ball in the previous question.

41) Going Bowling I

A bowling ball and a ping-pong ball are rolling toward you with the **same momentum**. If you exert the **same force** to stop each one, which takes a **longer time** to bring to rest?

- 1) the bowling ball
- 2) same time for both
- 3) the ping-pong ball
- 4) impossible to say



41) Going Bowling I

A bowling ball and a ping-pong ball are rolling toward you with the **same momentum**. If you exert the **same force** to stop each one, which takes a **longer time** to bring to rest?

1) the bowling ball

2) same time for both

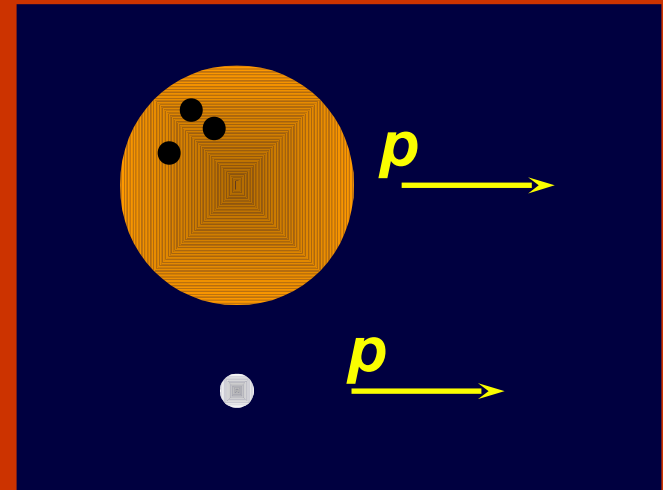
3) the ping-pong ball

4) impossible to say

We know: $F_{av} = \frac{\Delta p}{\Delta t}$ so $\Delta p = F_{av} \Delta t$

Here, F and Δp are the **same** for both balls!

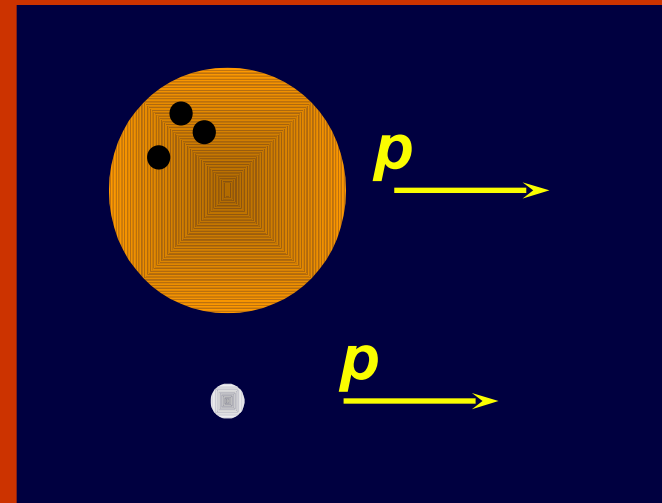
It will take the **same amount of time** to stop them.



42) Going Bowling II

A bowling ball and a ping-pong ball are rolling toward you with the **same momentum**. If you exert the **same force** to stop each one, for which is the **stopping distance** greater?

- 1) the bowling ball
- 2) same distance for both
- 3) the ping-pong ball
- 4) impossible to say

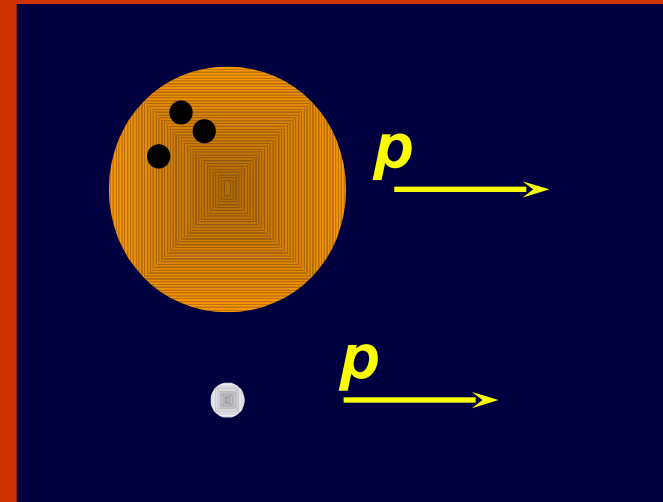


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- 1) the bowling ball
- 2) same distance for both
- 3) the ping-pong ball
- 4) impossible to say

Use the work-energy theorem: $W = \Delta KE$. The ball with **less mass** has the **greater speed (why?)**, and thus the **greater KE (why again?)**. In order to remove that KE, work must be done, where $W = Fd$. Since the force is the **same** in both cases, the distance needed to stop the **less massive ball** must be **bigger**.

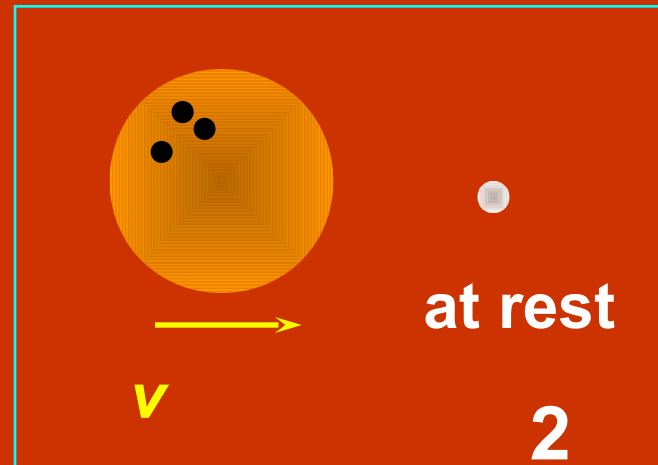


43) Elastic Collisions I

Consider two elastic collisions:

- 1) a golf ball with speed v hits a stationary bowling ball head-on.
- 2) a bowling ball with speed v hits a stationary golf ball head-on. In which case does the golf ball have the greater speed after the collision?

- 1) situation 1
- 2) situation 2
- 3) both the same



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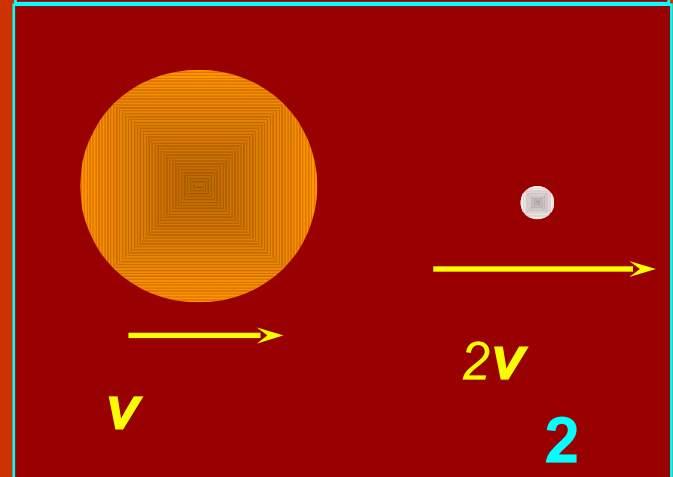
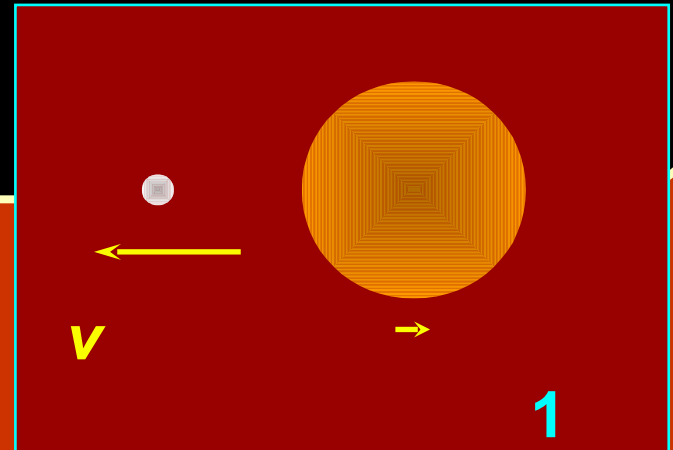
2) situation 2

3) both the same

Remember that the magnitude of the *relative velocity* has to be equal before and after the collision!

In case 1 the bowling ball will almost remain at rest, and the golf ball will bounce back with speed close to v .

In case 2 the bowling ball will keep going with speed close to v , hence the golf ball will rebound with speed close to $2v$.



44) Elastic Collisions II

Carefully place a small rubber ball (mass m) on top of a much bigger basketball (mass M) and drop these from some height h . What is the velocity of the smaller ball after the basketball hits the ground, reverses direction, and then collides with small rubber ball?

- 1) zero
- 2) v
- 3) $2v$
- 4) $3v$
- 5) $4v$

44) Elastic Collisions II

Carefully place a small rubber ball (mass m) on top of a much bigger basketball (mass M) and drop these from some height h . What is the velocity of the smaller ball after the basketball hits the ground, reverses direction, and then collides with small rubber ball?

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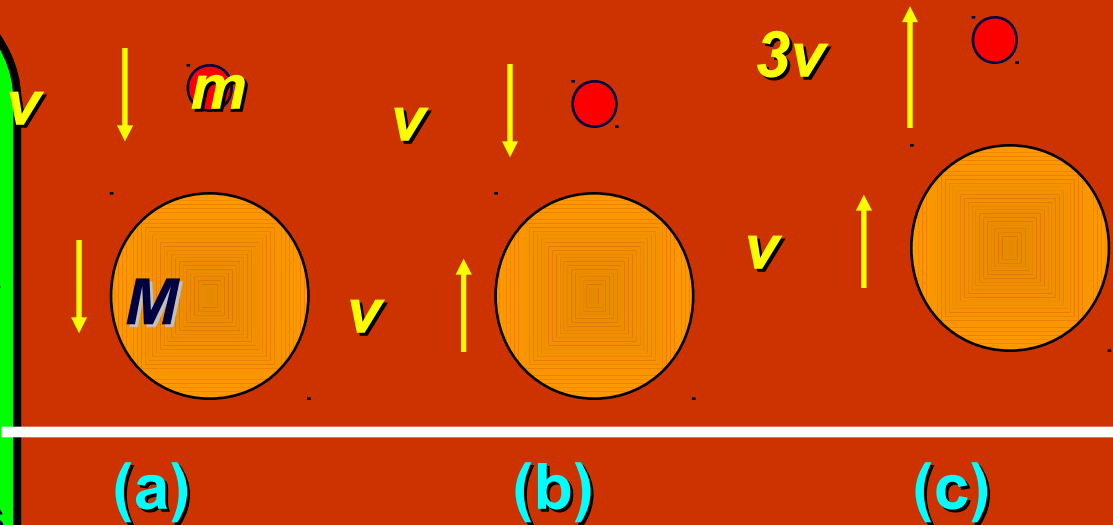
2) v

3) $2v$

4) $3v$

5) $4v$

Remember that **relative velocity** has to be equal before and after collision! Before the collision, the basketball bounces up with v and the rubber ball is coming down with v , so their relative velocity is $-2v$. After the collision, it therefore has to be $+2v$!

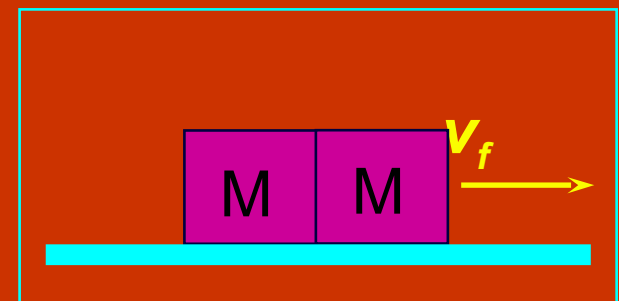
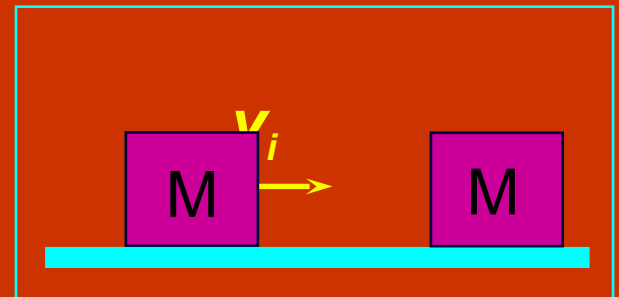


Follow-up: With initial drop height h , how high does the small rubber ball bounce up?

45) Inelastic Collisions I

A box slides with initial velocity **10 m/s** on a frictionless surface and collides inelastically with an identical box. The boxes stick together after the collision. What is the final velocity?

- 1) 10 m/s
- 2) 20 m/s
- 3) 0 m/s
- 4) 15 m/s
- 5) 5 m/s



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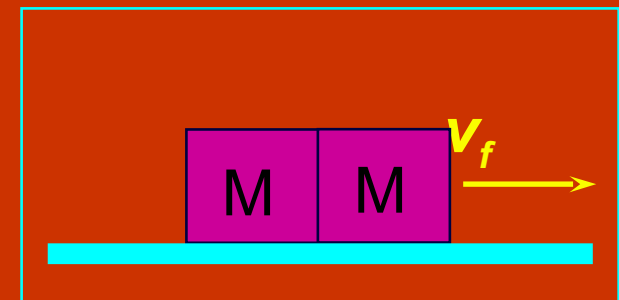
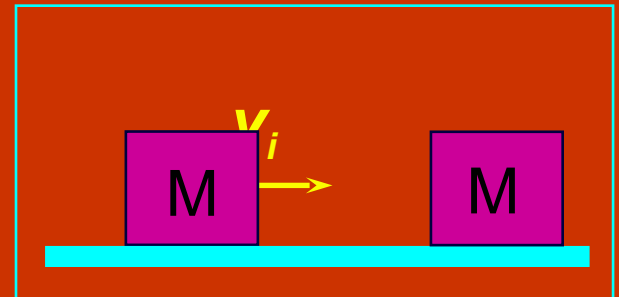
The initial momentum is:

$$M v_i = (10) M$$

The final momentum must be the same!!

The final momentum is:

$$M_{\text{tot}} v_f = (2M) v_f = (2M) (5)$$



46) Inelastic Collisions II

On a frictionless surface, a sliding box collides and sticks to a second identical box which is initially at rest.

What is the final KE of the system in terms of the initial KE?

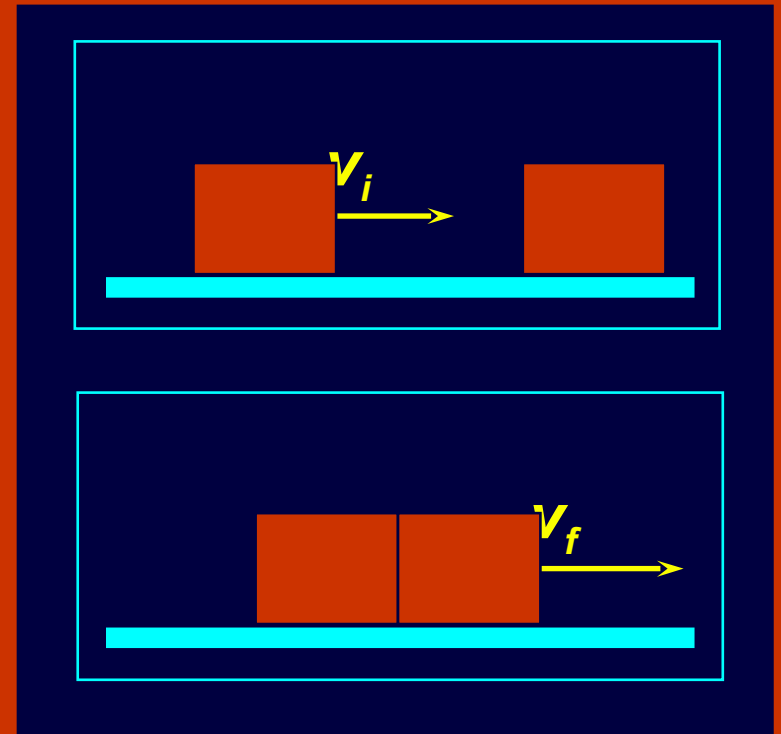
1) $KE_f = KE_i$

2) $KE_f = KE_i / 4$

3) $KE_f = KE_i / \sqrt{2}$

4) $KE_f = \underline{KE_i} / 2$

5) $KE_f = \sqrt{2} KE_i$



46) Inelastic Collisions II

On a frictionless surface, a sliding box collides and sticks to a second identical box which is initially at rest. What is the final KE of the system in terms of the initial KE?

1) $KE_f = KE_i$

2) $KE_f = KE_i / 4$

3) $KE_f = KE_i / \sqrt{2}$

4) $KE_f = KE_i / 2$

5) $KE_f = \sqrt{2} KE_i$

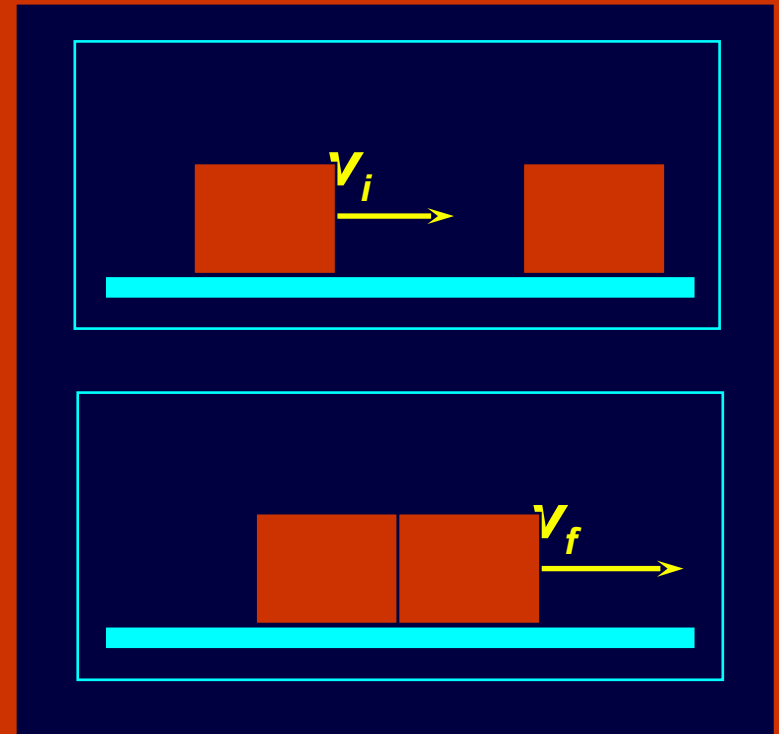
Momentum: $mv_i + 0 = (2m)v_f$

So we see that: $v_f = 1/2 v_i$

Now, look at kinetic energy:

First, $KE_i = 1/2 mv_i^2$

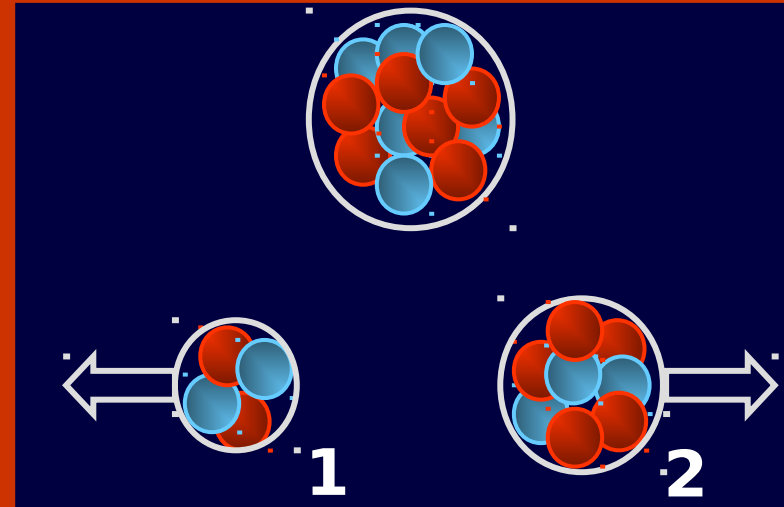
So: $KE_f = 1/2 m_f v_f^2$
 $= 1/2 (2m) (1/2 v_i)^2$
 $= 1/2 (1/2 mv_i^2)$
 $= 1/2 KE_i$



47) Nuclear Fission I

A uranium nucleus (at rest) undergoes fission and splits into two fragments, one heavy and the other light. Which fragment has the greater momentum?

- 1) the heavy one
- 2) the light one
- 3) both have the same momentum
- 4) impossible to say

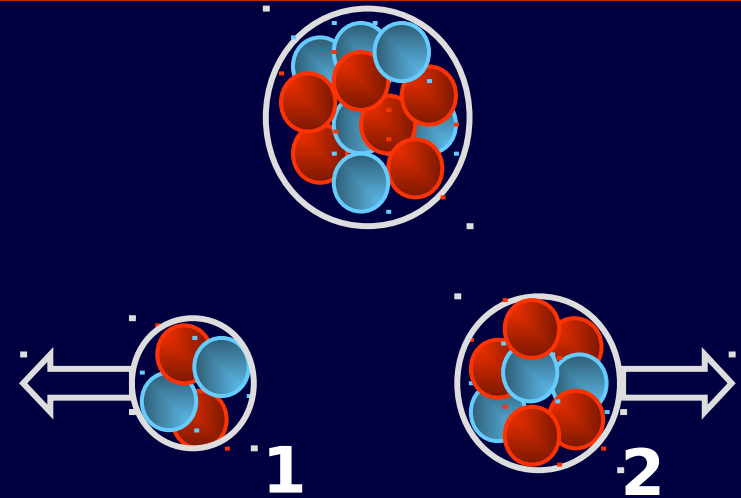


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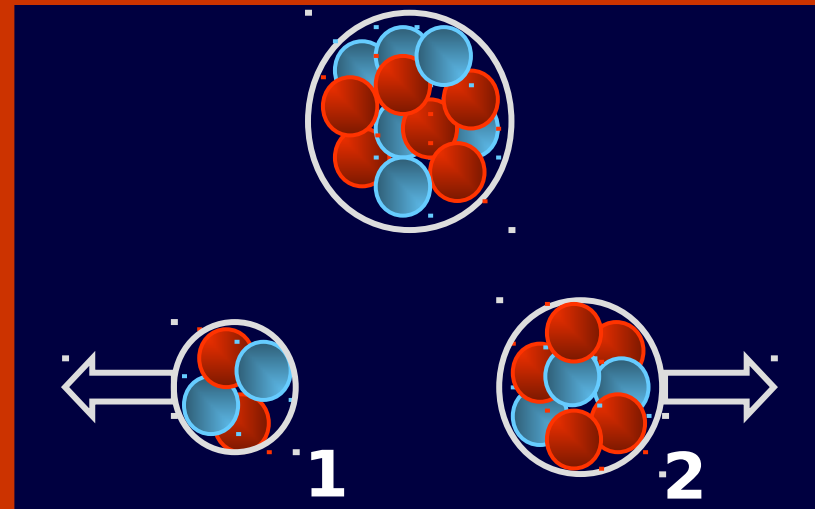
The initial momentum of the uranium was zero, so the final total momentum of the two fragments must also be zero. Thus the individual momenta are equal in magnitude and opposite in direction.



48) Nuclear Fission II

A uranium nucleus (at rest) undergoes fission and splits into two fragments, one heavy and the other light. Which fragment has the greater speed?

- 1) the heavy one
- 2) the light one
- 3) both have the same speed
- 4) impossible to say

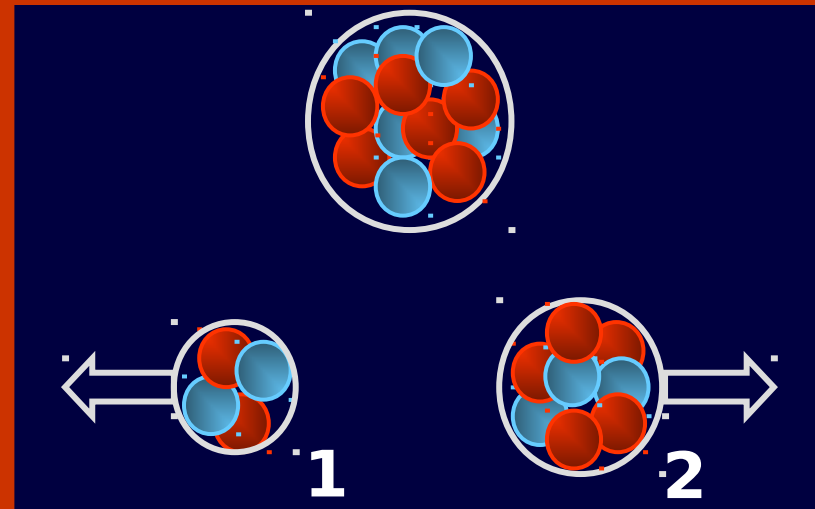


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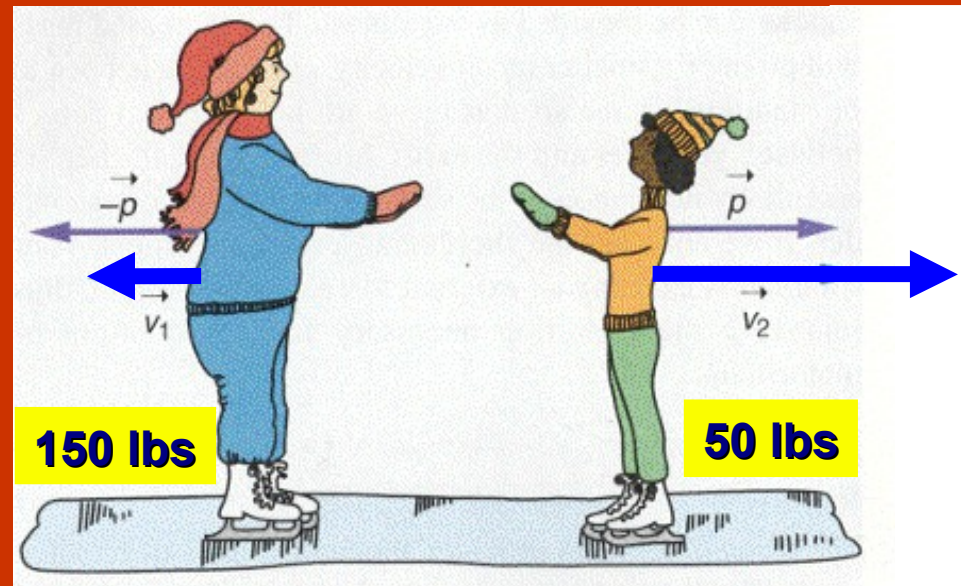
We have already seen that the individual momenta are equal and opposite. In order to keep the magnitude of momentum mv the same, the heavy fragment has the lower speed and the light fragment has the greater speed.



49) Recoil Speed I

Amy (150 lbs) and Gwen (50 lbs) are standing on slippery ice and push off each other. If Amy slides at 6 m/s, what speed does Gwen have?

- (1) 2 m/s
- (2) 6 m/s
- (3) 9 m/s
- (4) 12 m/s
- (5) 18 m/s

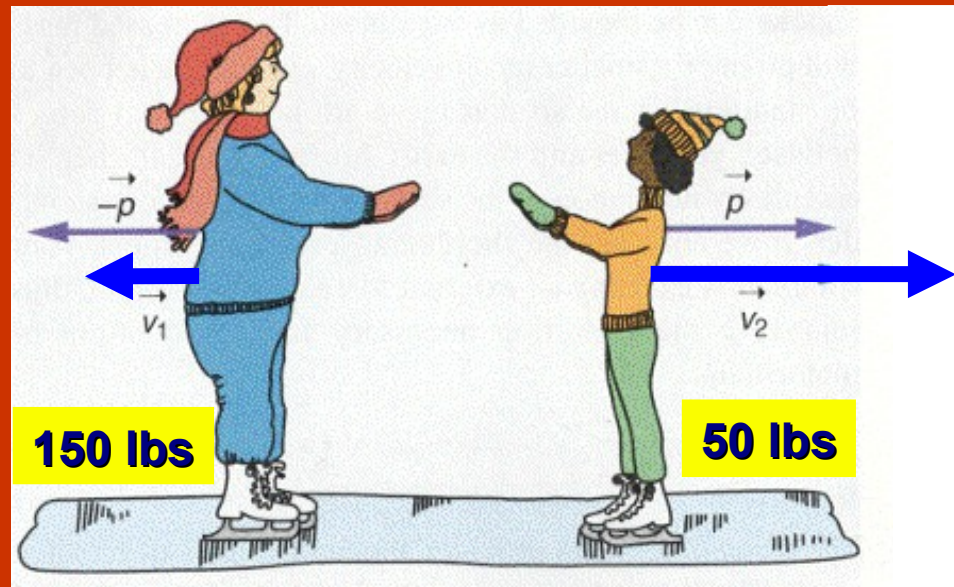


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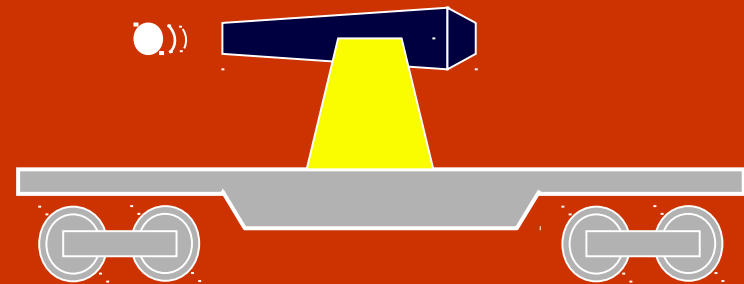
The initial momentum is zero, so the momenta of Amy and Gwen must be equal and opposite. Since $p = mv$, then if Amy has 3 times more mass, we see that Gwen must have 3 times more speed.



50) Recoil Speed II

A cannon sits on a stationary railroad flatcar with a total mass of **1000 kg**. When a **10-kg** cannon ball is fired to the left at a speed of **50 m/s**, what is the recoil speed of the flatcar?

- 1) 0 m/s
- 2) 0.5 m/s to the right
- 3) 1 m/s to the right
- 4) 20 m/s to the right
- 5) 50 m/s to the right



50) Recoil Speed II

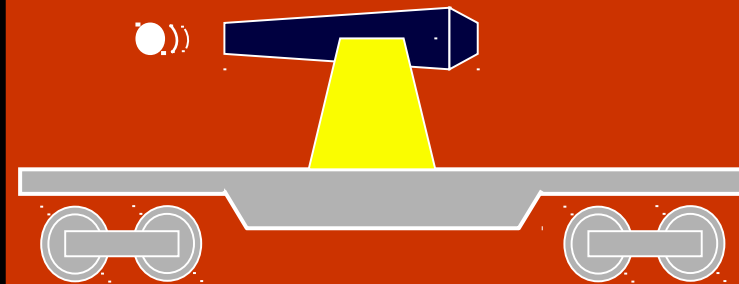
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- 1) 0 m/s
- 2) 0.5 m/s to the right
- 3) 1 m/s to the right
- 4) 20 m/s to the right
- 5) 50 m/s to the right

Since the initial momentum of the system was zero, the final total momentum must also be zero. **Thus, the final momenta of the cannon ball and the flatcar must be equal and opposite.**

$$p_{\text{cannonball}} = (10 \text{ kg})(50 \text{ m/s}) = 500 \text{ kg}\cdot\text{m/s}$$

$$p_{\text{flatcar}} = 500 \text{ kg}\cdot\text{m/s} = (1000 \text{ kg})(0.5 \text{ m/s})$$



51) Gun Control

When a bullet is fired from a gun, the bullet and the gun have equal and opposite momenta. If this is true, then why is the bullet deadly? (whereas it is safe to hold the gun while it is fired)

- 1) it is much sharper than the gun
- 2) it is smaller and can penetrate your body
- 3) it has more kinetic energy than the gun
- 4) it goes a longer distance and gains speed
- 5) it has more momentum than the gun

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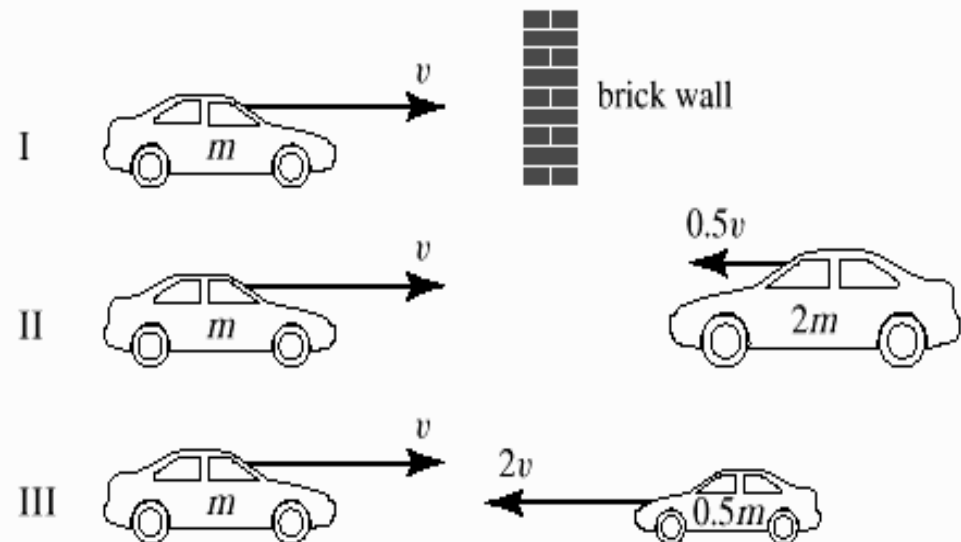
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- 2) it is smaller and can penetrate your body
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While it is true that the magnitudes of the momenta of the gun and the bullet are equal, the bullet is less massive and so it has a much higher velocity. Since KE is related to v^2 , the bullet has considerably more KE and therefore can do more damage on impact.

52) Crash Cars I

If all three collisions below are **totally inelastic**, which one(s) will bring the car on the left to a complete halt?

- 1) I
- 2) II
- 3) I and II
- 4) II and III
- 5) all three



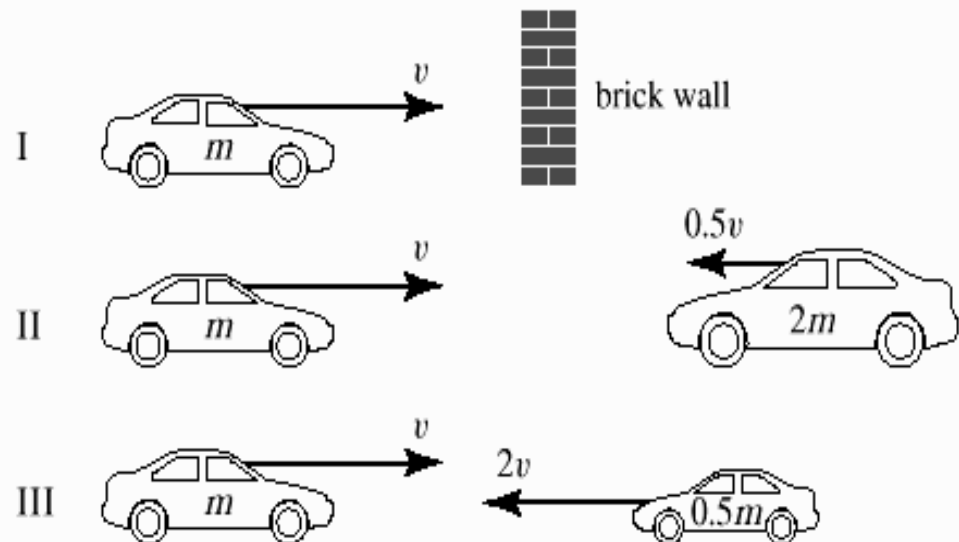
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In case I, the solid wall clearly stops the car.

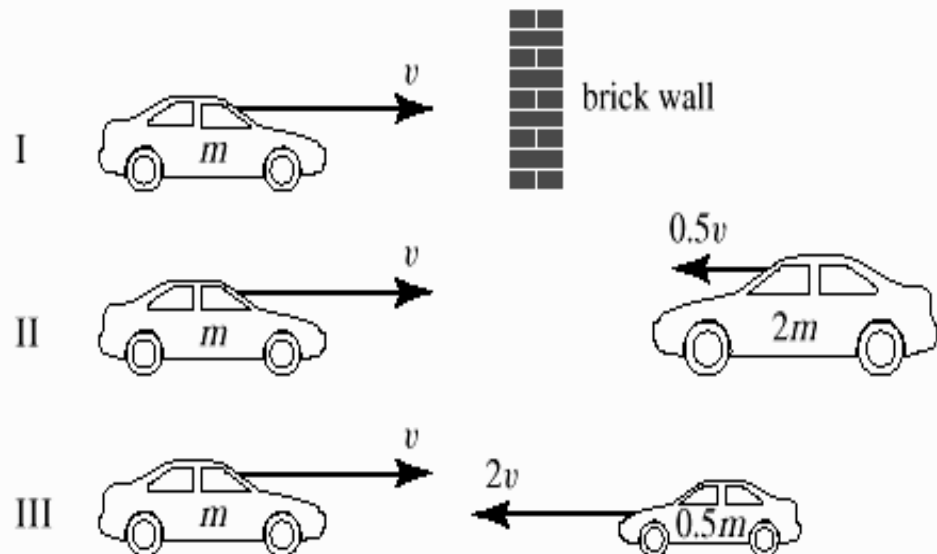
In cases II and III, since $p_{tot} = 0$ before the collision, then p_{tot} must also be zero after the collision, which means that the car comes to a halt in all three cases.



53) Crash Cars II

If all three collisions below are **totally inelastic**, which one(s) will cause the most damage (in terms of lost energy)?

- 1) I
- 2) II
- 3) III
- 4) II and III
- 5) all three



53) Crash Cars II

If all three collisions below are **totally inelastic**, which one(s) will cause the most damage (in terms of lost energy)?

1) I

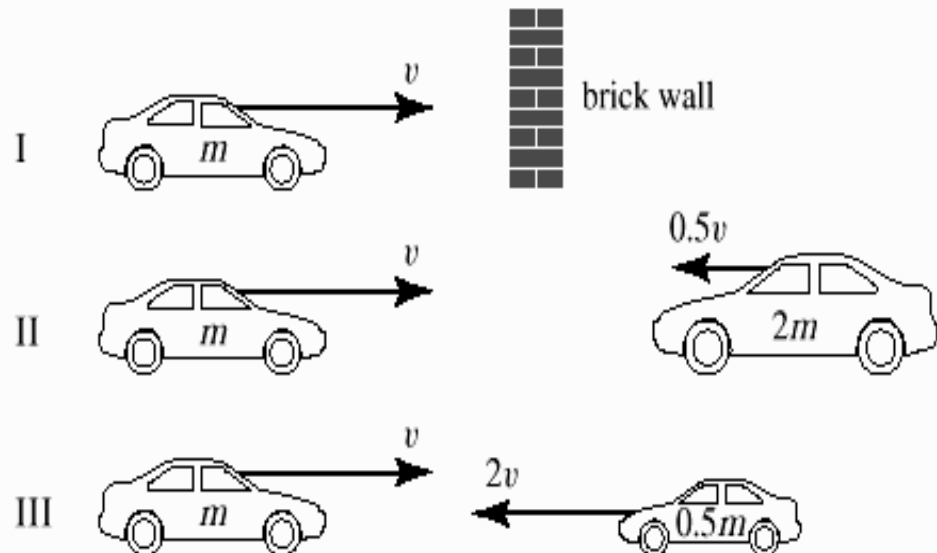
2) II

3) III

4) II and III

5) all three

The car on the left loses the same KE in all 3 cases, but in **case III**, the car on the right loses the most KE because $KE = 1/2 m v^2$ and the car in **case III** has the largest velocity.



54) Shut the Door!

You are lying in bed and you want to shut your bedroom door. You have a **superball** and a **blob of clay** (both with the same mass) sitting next to you.

Which one would be more effective to throw at your door to close it?

- 1) the superball
- 2) the blob of clay
- 3) it doesn't matter -- they will be equally effective
- 4) you are just too lazy to throw anything

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- 4) you are just too lazy to throw anything

The superball bounces off the door with almost no loss of speed, so its Δp (and that of the door) is $2mv$.

The clay sticks to the door and continues to move along with it, so its Δp is less than that of the superball, and therefore it imparts less Δp to the door.