Physics 131- Fundamentals of Physics for Biologists I

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Quiz 10

Energy

In many of your science classes you talk about "energy."

What is it?

Write down:

one word or sentence or picture

one equation

Hold up your whiteboards

Whiteboard, TA & LA

Energy

- N2 tells us that a force can change an object's velocity in one of two ways:
  - It can change the speed
  - It can change the direction
- Analyzing changes in speed leads us to study energy.
- Analyzing changes in direction leads us to study rotations.

Kinetic Energy and Work

Consider an object moving along a line feeling a single force F

When it moves a distance Δx, how much does its speed change?

$$a = F^{net} / m$$

$$\frac{\Delta v}{\Delta t} = \frac{F^{net}}{m}$$

$$\frac{\Delta v}{\Delta t} \Delta x = \frac{F^{net}}{m} \Delta x$$

$$\Delta v \frac{\Delta x}{\Delta t} = \frac{F^{net} \Delta x}{m}$$

$$\Delta v \frac{\Delta x}{\Delta t} = \frac{F^{net} \Delta x}{m}$$

$$\langle v \rangle \Delta v = \frac{F^{net} \Delta x}{m}$$

$$\frac{v_i + v_f}{2}(v_f - v_i) = \frac{F^{net} \Delta x}{m}$$

$$\tfrac{1}{2}(v_f^2 - v_i^2) = \frac{F^{net} \Delta x}{m}$$

$$\tfrac{1}{2} m(v_f^2 - v_i^2) = F^{net} \Delta x$$

Definitions:

Kinetic energy = $\tfrac{1}{2} mv^2$

Work done by a force F = $F \, \Delta x$

Result

$$\Delta(\tfrac{1}{2} mv^2) = F^{net} \, \Delta x$$

Work Energy Theorem

Dimensions and Units of Energy and Work

- $[1/2\, mv^2] = M\text{-}(L/T)^2 = ML^2/T^2$
- $1\ kg\text{-}m^2/s^2 = 1\ N\text{-}m = 1$ Joule
- Other units of energy are common (and will be discussed later)
  - Calorie
  - eV (electron Volt)

The diagram depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.

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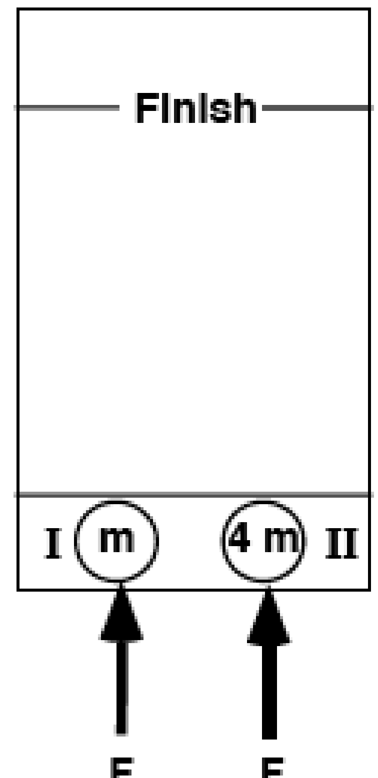

Which puck will have the greater **kinetic energy** upon reaching the finish line?

1. Puck I
2. Puck II
3. Both will have the same.
4. There is not enough information to decide.

The diagram depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.

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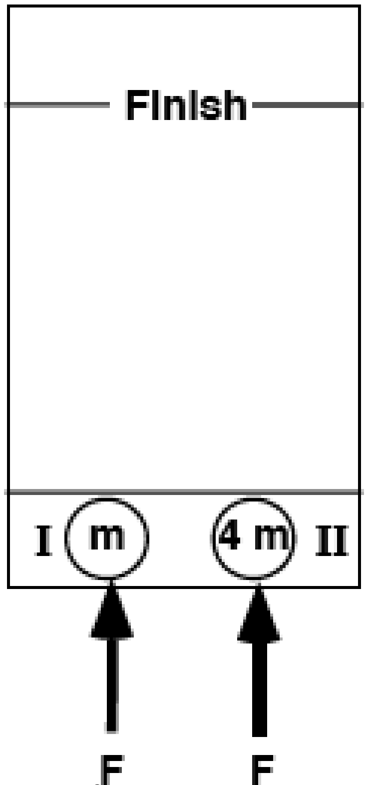
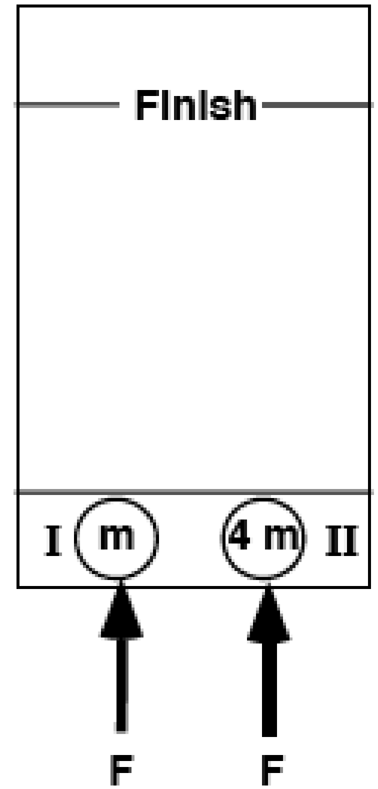


Which puck will have the greater **velocity** upon reaching the finish line?

1. Puck I
2. Puck II
3. Both will have the same.
4. There is not enough information to decide.

The diagram depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.

Whiteboard, TA & LA

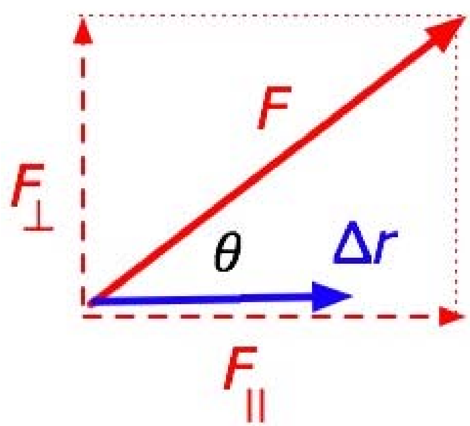


Which puck will have the greater **momentum** upon reaching the finish line?

1. Puck I
2. Puck II
3. Both will have the same.
4. There is not enough information to decide.

Work in another direction: The dot product

- Suppose we are moving along a line, but the force we are interested in in pointed in another direction? (How can this happen?)
- Only the part of the force in the direction of the motion counts to change the speed (energy).



$$\text{Work} = F_{||}\,\Delta r = F\cos\theta\,\Delta r \equiv \vec{F}\cdot\Delta\vec{r}$$

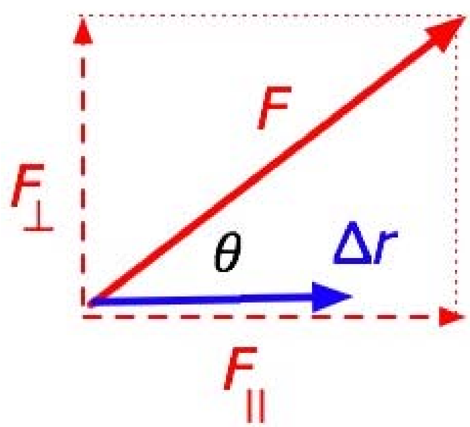
Dot products in general

$$F_{||}\,\Delta r \equiv \vec{F}\cdot\Delta\vec{r} \qquad\qquad \vec{F}\cdot\Delta\vec{r} = F\cos\theta\,\Delta r$$

In general, for any two vectors that have an angle θ between them, the dot product is defined to be

$$\vec{a}\cdot\vec{b} = ab\cos\theta$$

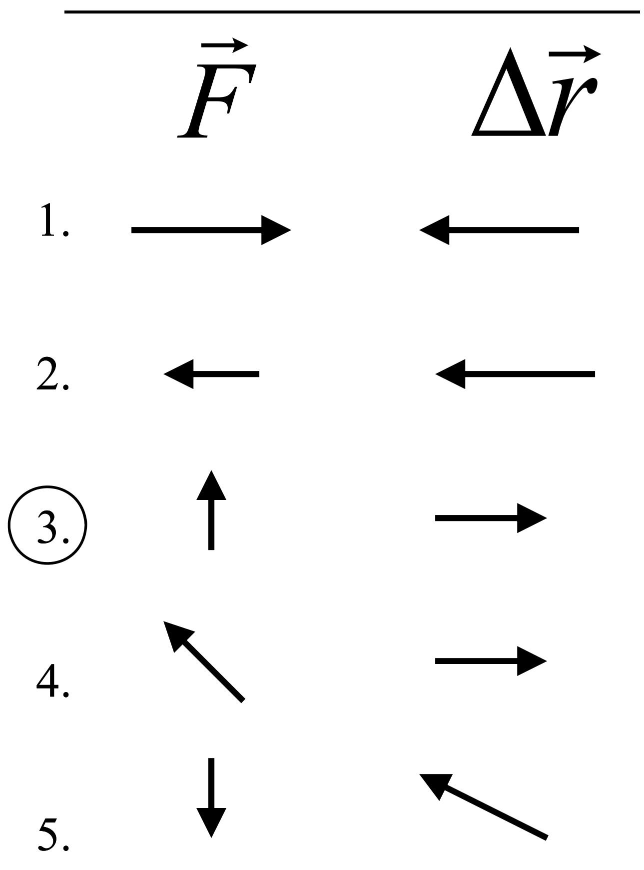
$$\vec{a}\cdot\vec{b} = a_x b_x + a_y b_y$$



The dot product is a scalar.
Its value does not depend on the coordinate system we select.

Each row in the following table pairs a force vector with a corresponding displacement resulting in work *W* being done.

In which of these rows is the work done zero?



6. None of the above

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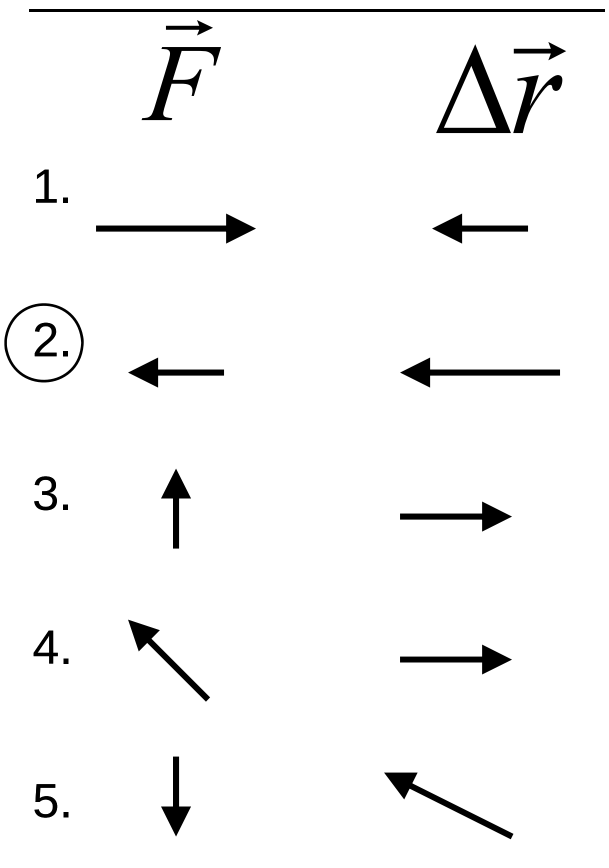
Each row in the following table pairs a force vector with a corresponding displacement resulting in work W being done.

In which of these rows is the work done positive?



6. None of the above

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Foothold ideas: Kinetic Energy and Work

- Newton's laws tell us how velocity changes. The Work-Energy theorem tells us how speed (independent of direction) changes.
- Kinetic energy = $\frac{1}{2}mv^2$
- Work done by a force = $F_x \Delta x$ or $F_{\parallel} \Delta r$ (part of force parallel to displacement)
- Work-energy theorem: $\Delta(\frac{1}{2}mv^2) = F_{\parallel}^{net} \Delta r$

Simplest example:

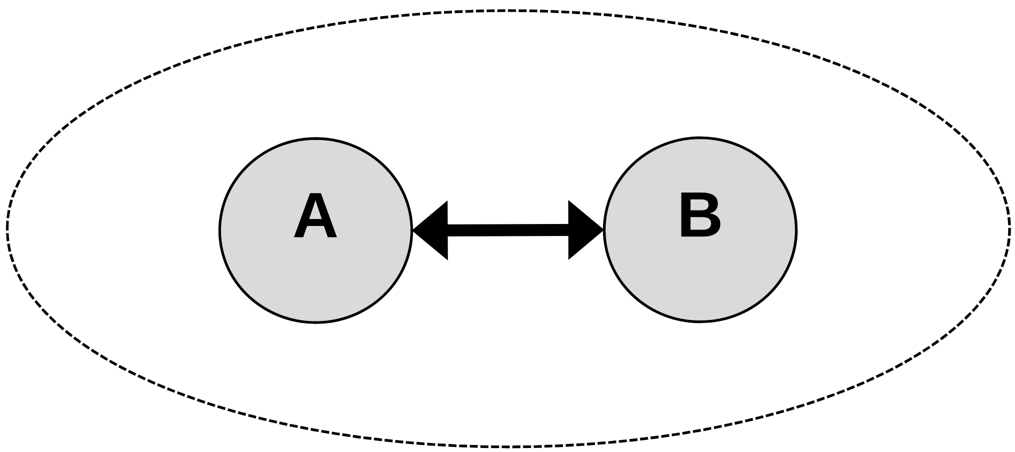
Consider the motion of two objects during a short time interval while they exert forces on each other.

Momentum change?

Impulse-momentum theorem!

$$\Delta\vec{p}_A = \vec{F}_{B\rightarrow A}\Delta t$$

$$\Delta\vec{p}_B = \vec{F}_{A\rightarrow B}\Delta t$$



Add and use N3!

$$\Delta\vec{p}_A + \Delta\vec{p}_B = \vec{F}_{B\rightarrow A}\Delta t + \vec{F}_{A\rightarrow B}\Delta t = (\vec{F}_{B\rightarrow A} + \vec{F}_{A\rightarrow B})\Delta t = 0$$

Momentum Conservation!

Simplest example:

Consider the motion of two objects during a short time interval while they exert forces on each other.

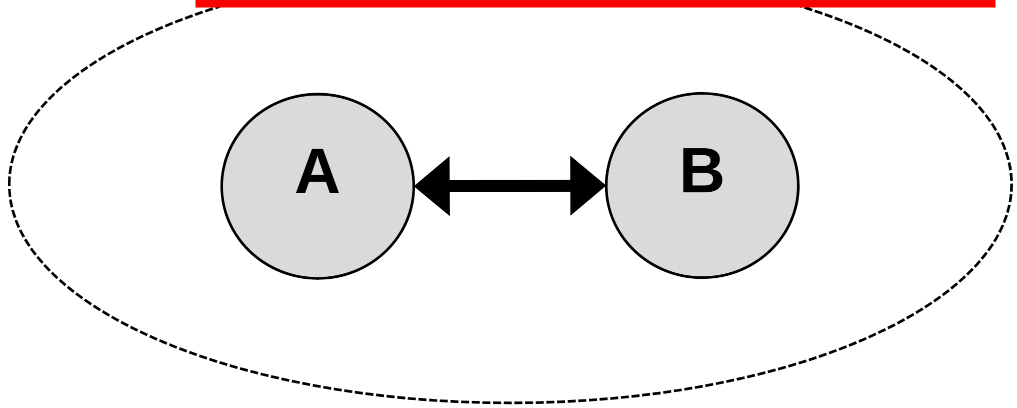
KE change?

Work-energy theorem!

They may each be moving so although the times are the same, the distances might NOT be!

$$\Delta KE_A = \vec{F}_{B\rightarrow A} \cdot \Delta \vec{r}_A$$

$$\Delta KE_B = \vec{F}_{A\rightarrow B} \cdot \Delta \vec{r}_B$$



Add and use N3!

$$\Delta KE_A + \Delta KE_B = \vec{F}_{B\rightarrow A} \cdot \Delta \vec{r}_A + \vec{F}_{A\rightarrow B} \cdot \Delta \vec{r}_B$$

$$= \vec{F}_{B\rightarrow A} \cdot \left(\Delta \vec{r}_A - \Delta \vec{r}_B\right) \neq 0$$

??!

16

Foothold ideas: Potential Energy

- For some forces between objects (gravity, electricity, springs) the work only depends of the change in relative position of the objects. Such forces are called <u>*conservative*</u>.
- For these forces the work done by them can be written

$$\vec{F} \cdot \Delta\vec{r}_{rel} = -\Delta U$$

- *U* is called a *potential energy* and can be considered an <u>*energy of place belonging to the two objects that can be exchanged with KE.*</u>

Foothold ideas: Potential Energy

- For some forces work only depends on the change in position. Then the work done can be written $$\vec{F} \cdot \Delta\vec{r} = -\Delta U$$

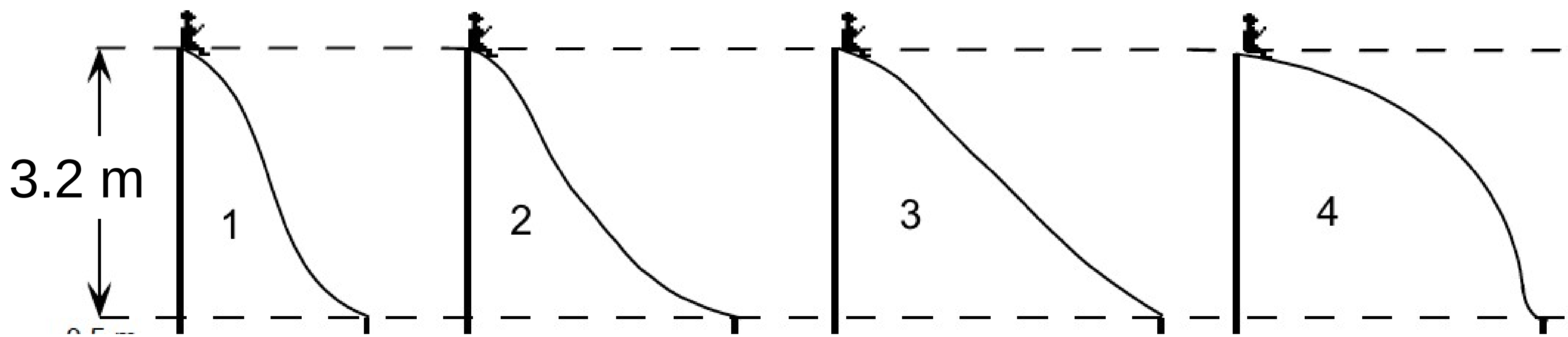
  U is called a *potential energy*.

- For gravity, $U_{gravity} = mgh$

  For a spring, $U_{spring} = ½\, kx^2$

  For electric force, $U_{electric} = k_C Q_1 Q_2 / r_{12}$

A young girl wants to select one of the (frictionless) playground slides illustrated below to give her the greatest possible speed when she reaches the bottom of the slide. Which should she choose?



1. 1
2. 2
3. 3
4. 4
5. She should jump straight down
6. It doesn't matter. It would be the same for each.

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