Welcome back to Physics 215

Today's agenda:

- *Work*
- *Potential Energy*
- *Power*

Work and Kinetic Energy in 2D

Work done by object 2 on object 1:

Kinetic energy of an object:

$$K = \tfrac{1}{2}mv^2 \quad [\text{or: } \tfrac{1}{2}m(\vec{v}\bullet\vec{v})]$$

Scalar (or "dot") product of vectors

The scalar product is a way to combine two vectors to obtain a number (or *scalar*). It is indicated by a dot (•) between the two vectors.

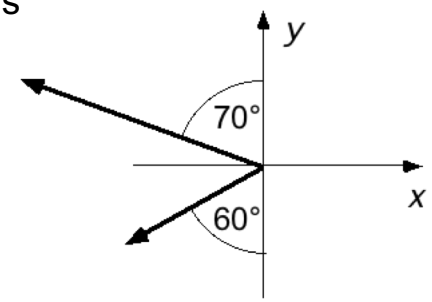
(Note: component of A in direction n is just A•n)

$$\vec{A} \bullet \vec{B} = AB\cos\theta$$

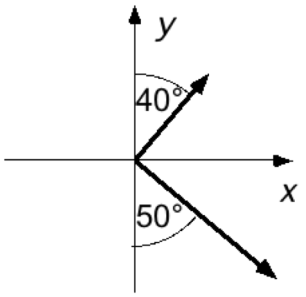
$$= A_x B_x + A_y B_y + A_z B_z$$

SG Is the scalar ("dot") product of the two vectors

A. positive
B. negative
C. equal to zero
D. "Can't tell."



SG Is the scalar ("dot") product of the two vectors

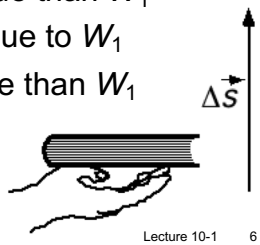


A. positive
B. negative
C. equal to zero
D. "Can't tell."

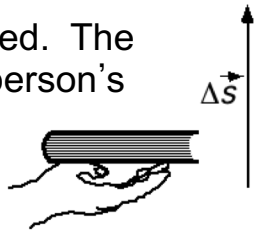
SG A person lifts a book at constant speed. Since the force exerted on the book by the person's hand is in the same direction as the displacement of the book, the work (W_1) done on the book by the person's hand is positive.

The work done on the book by the earth is:

A. negative and equal in absolute value to W_1
B. negative and less in absolute value than W_1
C. positive and equal in absolute value to W_1
D. positive and less in absolute value than W_1



A person lifts a book at constant speed. The work (W_1) done on the book by the person's hand is positive.



Work done on the book by the earth:

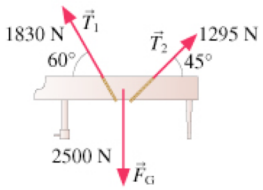
Net work done on the book:

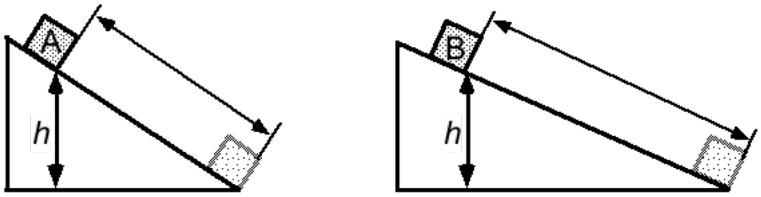
Change in kinetic energy of the book:

SG A person carries a book horizontally at constant speed. The work done on the book by the person's hand is

A. positive
B. negative
C. equal to zero
D. "Can't tell."

Sample problem: The two ropes seen in the figure are used to lower a 255 kg piano 5.1 m from a second-story window to the ground. How much work is done by each of the three forces?





SG Two identical blocks slide down two frictionless ramps. Both blocks start from the same height, but block A is on a steeper incline than block B.

Using the work-kinetic energy theorem, the speed of block A at the bottom of its ramp is

A. less than the speed of block B.
B. equal to the speed of block B.
C. greater than the speed of block B.
D. "Can't tell."

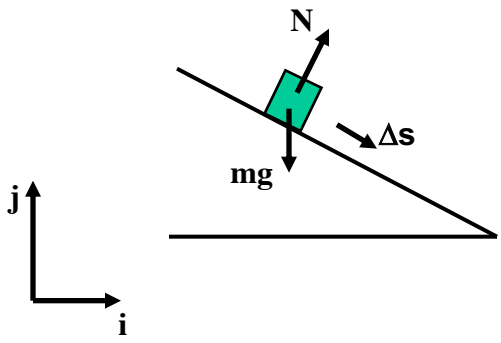
Reading for Thursday

- Potential energy
- Reading 8.1-8.5

Solution

- Which forces do work on block?
- Which, if any, are constant?
- What is $\mathbf{F} \cdot \Delta \mathbf{s}$ for motion?

Work done by gravity



Work $W = -mg\ j \bullet \Delta s$

Therefore,

$W = -mg\Delta h$

N does no work!

Work done on an object by gravity

$$W_{(by\ \text{earth on object})} = -\,m\,g\,\Delta h,$$

where $\Delta h = h_{final} - h_{initial}$ is the change in height.

Object moves	Change in height Δh	Work done on object by earth
upward	positive	negative
downward	negative	positive

Defining gravitational potential energy

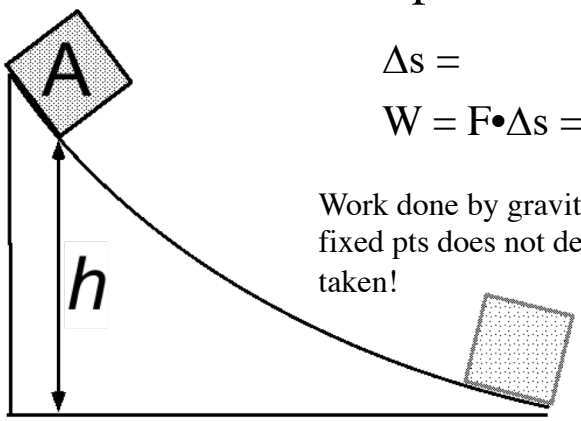
$$W_{(\text{on obj. by earth})} = \Delta K$$

$$0 = \Delta K - W_{(\text{on obj. by earth})}$$

$$0 = \Delta K + \Delta U_g$$

The *change* in gravitational potential energy of the object-earth system is just another name for the negative value of the work done on an object by the earth.

Curved ramp



$\Delta s =$

$W = F \bullet \Delta s =$

Work done by gravity between 2 fixed pts does not depend on path taken!

Work done by gravitational force in moving some object along any path is *independent* of the path depending *only* on the change in vertical height

Demo: 4 tracks

Conservative forces

- If the work done by some force (e.g. gravity) does **not depend on path** the force is called **conservative**.
- Then gravitational potential energy U_g only depends on (vertical) position of object $U_g = U_g(h)$
- Elastic forces also conservative – elastic potential energy $U = (1/2)kx^2$...

Many forces

- For a particle which is subject to several (conservative) forces F_1, F_2 …

  $\Delta K = W_1 + W_2 + \ldots$ or equivalently:

  $\Delta K + \Delta U_1 + \Delta U_2 + \ldots = 0$

  i.e **$E = (1/2)mv^2 + U_1 + U_2 + \ldots$** is constant
- Principle called

  Conservation of total mechanical energy

Nonconservative forces

- Can do work, but cannot be represented by a potential energy function
  - examples: friction, air resistance
- Total mechanical energy can now change due to work done by nonconservative force

  $$\Delta K + \Delta U_1 + \Delta U_2 + \ldots = W_{\text{nonconservative}}$$

- For example, frictional force leads to decrease of total mechanical energy -- energy converted to heat, or internal energy
- Heat/internal energy is really just energy of molecular motion

Conservation of ***total*** energy

The total energy of an object or system is said to be conserved if the sum of **all** energies (including those outside of mechanics that have not yet been discussed) never changes.

This is believed always to be true.

Gravitational Potential Energy

For an object of mass m near the surface of the earth:

$$U_g = mgh$$

- h is height above arbitrary reference line
- Measured in Joules -- J (like kinetic energy)

Total energy for object moving under gravity

$E = U_g + K$ = constant

* E is called the (mechanical) energy

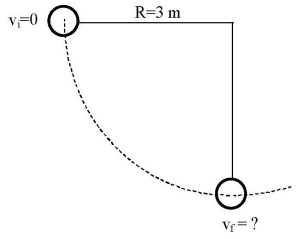
* It is conserved:

$(\frac{1}{2})\, mv^2 + mgh$ = constant

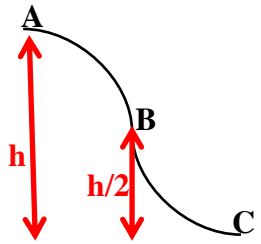
OR

Sample problem: A ball of mass m=7 kg attached to a massless string of length R=3 m is released from the position shown in the figure below. (a) Find magnitude of velocity of the ball at the lowest point on its path.

Small group:
(b) Find the tension in the string at that point

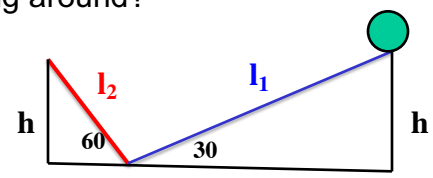


SG If the velocity at B is v, then what is the velocity at C?



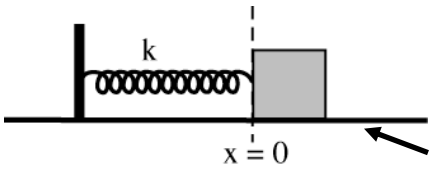
A. 2v
B. v
C. sqrt(2) v
D. v/sqrt(2)
E. None of the above

SG: Starting from a height h, a ball rolls down a frictionless shallow ramp of length $l_1 = h/\sin(30)$ with an angle 30 degrees, and then up a steep ramp of height h with angle 60 degrees and length $l_2 = h/\sin(60)$. How far up the steep ramp does the ball go before turning around?



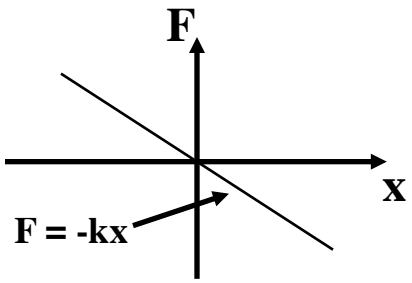
1. ½ l_2
2. l_1
3. l_1 sin(60)/sin(30)
4. l_2
5. None of the above

Springs -- Elastic potential energy



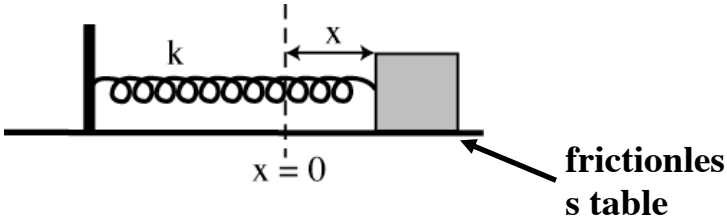
Force F = -kx (Hooke's law)

Area of triangle lying under straight line graph of F *vs*. x = (1/2)(+/-x)(-/+kx)



$$U_s = (1/2)kx^2$$

(Horizontal) Spring



- x = displacement from relaxed state of spring

- Elastic potential energy stored in spring: $U_s = (1/2)kx^2$

$$(1/2)kx^2 + (1/2)mv^2 = \text{constant}$$

SG A 0.5 kg mass is attached to a spring on a horizontal frictionless table. The mass is pulled to stretch the spring 5.0 cm and is released from rest. When the mass crosses the point at which the spring is not stretched, x = 0, its speed is 20 cm/s. If the experiment is repeated with a 10.0 cm initial stretch, what speed will the mass have when it crosses x = 0 ?

1. 40 cm/s
2. 0 cm/s
3. 20 cm/s
4. 10 cm/s

Sample problem: A 5.00-kg package slides 1.50 m down a long ramp that is inclined at 12.0° below the horizontal. The coefficient of kinetic friction between the package and the ramp is $\mu_k = 0.310$. Calculate: (a) the work done on the package by friction; (b) the work done on the package by gravity; (c) the work done on the package by the normal force; (d) the total work done on the package. (e) If the package has a speed of 2.20 m/s at the top of the ramp, what is its speed after sliding 1.50 m down the ramp?

Power

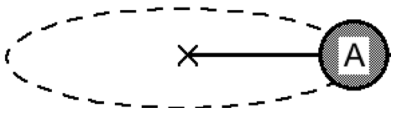
Power = Rate at which work is done

$$\text{Average power} = \frac{W}{\Delta t}$$

$$\text{Inst. power} = \lim_{\Delta t \to 0} \frac{W}{\Delta t}$$

Units of power:

SG A ball is whirled around a horizontal circle at constant speed.



If air drag forces can be neglected, the power expended by the hand is:

A. positive
B. negative
C. zero
D. "Can't tell."

SG A sports car accelerates from zero to 30 mph in 1.5 s. How long does it take to accelerate from zero to 60 mph, assuming the power ($=\Delta W / \Delta t$) of the engine to be constant?

(Neglect losses due to friction and air drag.)

A. 2.25 s
B. 3.0 s
C. 4.5 s
D. 6.0 s