Lecture 9

Energy
Work and Kinetic Energy
Kinetic and Potential Energy

Physics 105   Fall 2009

ENERGY

Energy is a property of the state of an object: hard to define precisely

Energy is a scalar quantity. It does not have a direction associated with it

Energy is conserved. It can be transferred from one object to another or change in form, but not created or destroyed.

Units: joule = $kg \cdot m^2/s^2$

Kinetic Energy

Kinetic Energy ≡ Energy of motion

$K = \frac{1}{2}mv^2$ for object moving with velocity v

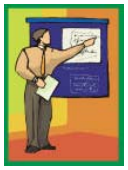
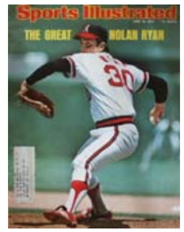
$$K = \frac{1}{2}mv^2 \qquad \left[\mathrm{J} = \mathrm{kg}\frac{\mathrm{m}^2}{\mathrm{s}^2}\right]$$

Kinetic Energy: Orders of Magnitude

$K = \frac{1}{2}mv^2$ for object moving with velocity v


Earth orbiting sun: 2×10^{29} J

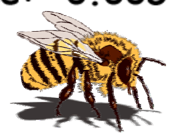
Car at 60 mph: 100,000 J

Nolan Ryan pitch: 300 J

Professor walking: 40 J

Angry bee: 0.005 J



Why $K = \frac{1}{2}mv^2$?

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Special case: Constant Acceleration

Remember result eliminating *t*: $\boxed{v^2 - v_0^{\,2} = 2a(x - x_0)}$

Multiply by ½ m: $\frac{1}{2}mv^2 - \frac{1}{2}mv_0^{\,2} = ma(x - x_0)$

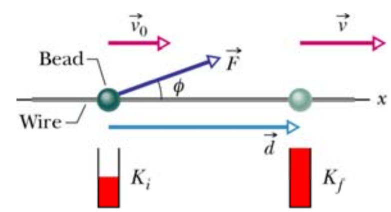
$= ma\Delta x$

But *F=ma!* $\Delta(\frac{1}{2}mv^2) = F\Delta x$

Energy and Work

Kinetic energy

$$K = \frac{1}{2}mv^2 \qquad \left[\mathrm{J} = \mathrm{kg}\frac{\mathrm{m}^2}{\mathrm{s}^2}\right]$$



Units of Work and Energy: Joule

Work done by a <u>constant</u> force

$$W = \vec{F}\cdot\vec{d} = Fd\cos\theta$$

Work-kinetic energy theorem

$$\Delta K = K_f - K_i = W$$

Work

Work $\equiv$ Energy transferred by a force

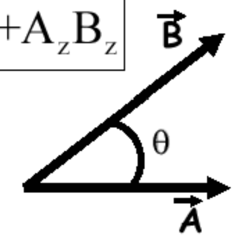
Work done on an object is the energy transferred to/from it

W > 0 $\rightarrow$ energy added
W < 0 $\rightarrow$ energy taken away

$\mathbf{W} = \vec{\mathbf{F}} \bullet \vec{\mathbf{r}}$ $\equiv$ Work done on an object by a constant force $\vec{\mathrm{F}}$ while moving through a displacement $\vec{\mathrm{r}}$

Dot Product: Physical Meaning

$$\boxed{\vec{\mathrm{A}} \bullet \vec{\mathrm{B}} = \mathrm{AB}\cos\theta = \mathrm{A_x B_x} + \mathrm{A_y B_y} + \mathrm{A_z B_z}}$$

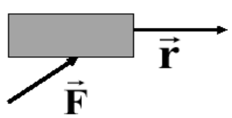


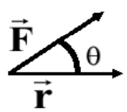
$$\theta = 0 \rightarrow \vec{\mathrm{A}} \bullet \vec{\mathrm{B}} = \mathrm{AB}$$

$$\theta = 90^o \rightarrow \vec{\mathrm{A}} \bullet \vec{\mathrm{B}} = 0$$

Dot product measures how much vectors are along each other

What does $\mathbf{W} = \vec{\mathbf{F}} \bullet \vec{\mathbf{r}}$ mean?





$$\mathrm{W} = \vec{\mathrm{F}} \bullet \vec{\mathrm{r}} = \mathrm{F_x r_x} + \mathrm{F_y r_y} = \mathrm{Fr}\cos\theta$$

W > 0 if θ < 90° $\longrightarrow$ force is adding energy to object

W < 0 if θ > 90° $\longrightarrow$ force is reducing energy of object

W = 0 if $\boxed{r = 0}$ or $\boxed{F = 0}$ or $\boxed{\vec{F} \perp \vec{r}}$

Work Examples

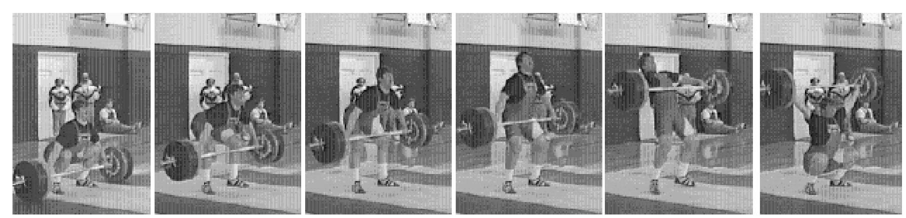
Push on a wall

W = 0 since wall does not move ($\vec{r}$ = 0)

Work due to Gravity

A weightlifter does work when lifting a weight

W=mgh
(h is the vertical drop)

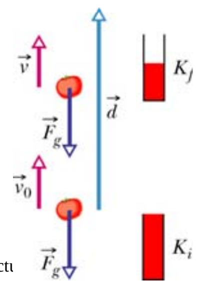


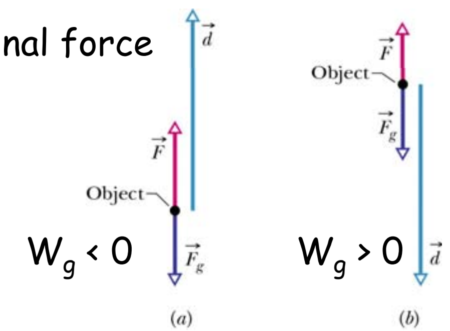
Work Done by a Gravitational Force

Work done by gravitational force

$$W_g = mgd\cos\theta$$

Tomato thrown upward



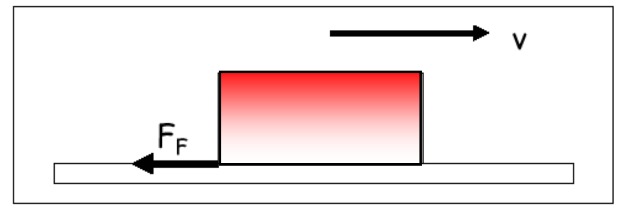


Lifting/lowering an object

Change in kinetic energy:

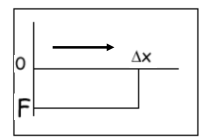
$$\Delta K = K_f - K_i = W_a + W_g$$

Work due to Friction



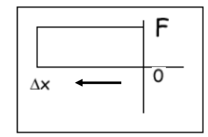
The frictional force always opposes the motion

Moving to the right



W=-|F| Δx
Δx>0

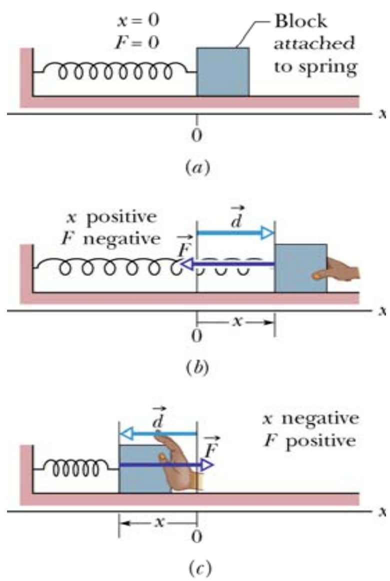
Moving to the left



W=+|F| Δx
Δx<0

W negative in both cases

Restoring Force

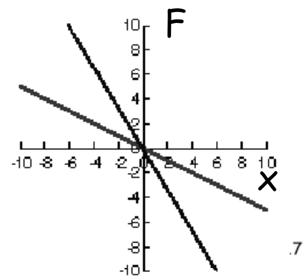


Equilibrium - no force

Stretched - force towards equilibrium point

F=-k x

Hooke's Law

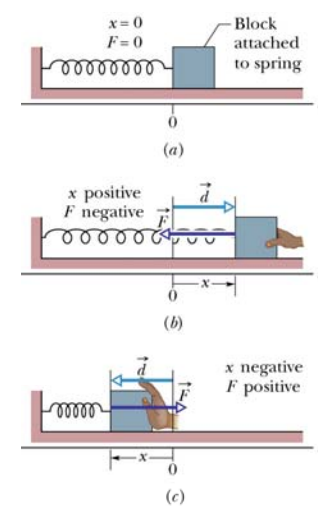


Work Done by a Spring Force

Hooke's law: $\vec{F} = -k\vec{d}$

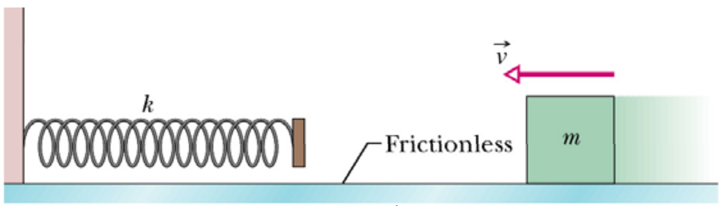
Work done by a spring force:

$$W_s = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$$

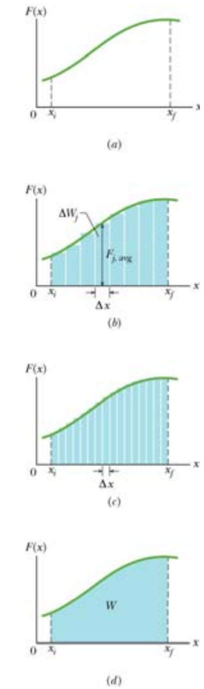


Sample Problem 7-8

A block of mass $m = 0.40\ kg$ slides across a horizontal frictionless counter with a speed of $v = 0.50\ m/s$. It runs into and compresses a spring of spring constant $k = 750\ N/m$. When the block is momentarily stopped by the spring, by what distance ***d*** is the spring compressed?



Work Done by a General Variable Force



Work: variable force

$$W = \int_{x_i}^{x_f} F(x)\, dx$$

- Calculus
- Divide area under curve
- Add increments of W (numerically)
- Analytical form?
- Integration!!!

Power

Work doesn't depend on the time interval

Work to climb a flight of stairs~3000 J 10 s / 1 min / 1 hour

Power is work done per unit time

Average Power $P_{avg} = \dfrac{W}{\Delta t}$

Instantaneous Power P = dW/dt = F dx/dt = Fv

Units $\dfrac{\text{Work}}{\text{time}}$ $\qquad \dfrac{1\ J}{1\ s} = 1$ Watt $\qquad$ 1 hp = 746 W

$P = \frac{1}{2}*50kg*(5m/s)^2/1\ s$

Power

Average Power

$$P_{avg} = \frac{W}{\Delta t}$$

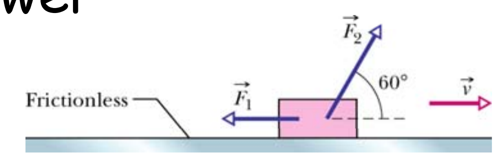
Units: Watts

Instantaneous Power

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

$$P = \vec{F} \cdot \vec{v}$$

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



Sample Problem 7-10: Two constant forces F_1 and F_2 acting on a box as the box slides rightward across a frictionless floor. Force F_1 is horizontal, with magnitude *2.0 N*, force F_2 is angled upward by *60°* to the floor and has a magnitude of *4.0 N*. The speed *v* of the box at a certain instant is *3.0 m/s*.

a) What is the power due to each force acting on the box? Is the net power changing at that instant?

b) If the magnitude F_2 is, instead, *6.0 N*, what is now the net power, and is it changing?

Quiz 9

1. As a sled is pulled by dogs across a flat, snow-covered field at a constant velocity, net work done on the sled is ________,

2. ...and work done by the air resistance and friction is ________,

3. ... and the work done by dogs is _________.

a) Positive
b) Zero
c) Negative

4. A 200-kg sled is moving along a flat road with initial velocity 5 m/s. A 10-N friction force is acting on the sled (dogs take some rest). The sled has traveled 100 m. What is its final kinetic energy?