Physics 101: Mechanics
Lecture 8

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Work and Kinetic Energy

- Work
- Kinetic Energy and the Work-Energy Theorem
- Work and Energy with Varying Forces
- Power

Why Energy?

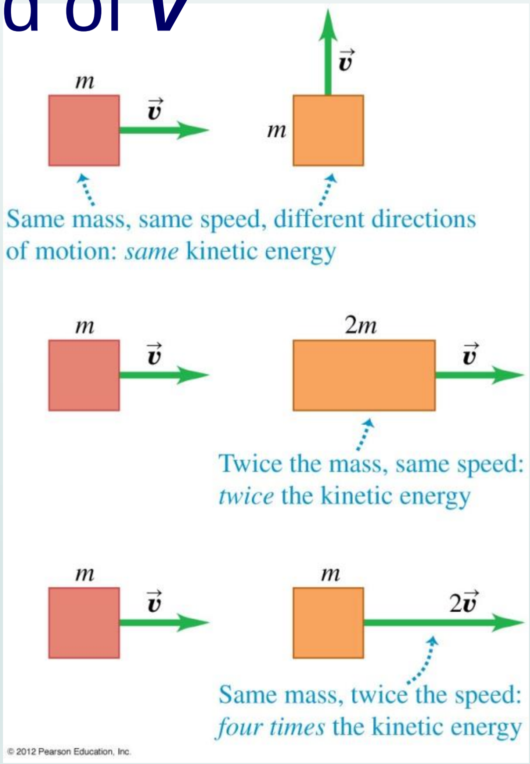
- Why do we need a concept of energy?
- The energy approach to describing motion is particularly useful when Newton’s Laws are difficult or impossible to use.
- Energy is a scalar quantity. It does not have a direction associated with it.

Kinetic Energy

- Kinetic Energy is energy associated with the state of motion of an object
- For an object moving with a speed of ***v***

$$K = \frac{1}{2} m v^2$$

- SI unit: joule (J)
- 1 joule = 1 J = 1 kg m^2/s^2



Kinetic Energy for Various Objects

$$KE = \frac{1}{2}mv^2$$

TABLE 7.1

Kinetic Energies for Various Objects

Object	Mass (kg)	Speed (m/s)	Kinetic Energy (J)
Earth orbiting the Sun	5.98×10^{24}	2.98×10^{4}	2.66×10^{33}
Moon orbiting the Earth	7.35×10^{22}	1.02×10^{3}	3.82×10^{28}
Rocket moving at escape speed[a]	500	1.12×10^{4}	3.14×10^{10}
Automobile at 65 mi/h	2 000	29	8.4×10^{5}
Running athlete	70	10	3 500
Stone dropped from 10 m	1.0	14	98
Golf ball at terminal speed	0.046	44	45
Raindrop at terminal speed	3.5×10^{-5}	9.0	1.4×10^{-3}
Oxygen molecule in air	5.3×10^{-26}	500	6.6×10^{-21}

[a] Escape speed is the minimum speed an object must reach near the Earth's surface to move infinitely far away from the Earth.

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Special case: Constant Acceleration

Remember result eliminating t:

$$v^2 - v_0^2 = 2a(x - x_0)$$

Multiply by ½ m:

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = ma(x - x_0)$$

$$= ma\Delta x$$

But $F=ma$!

$$\Delta(\frac{1}{2}mv^2) = F\Delta x$$

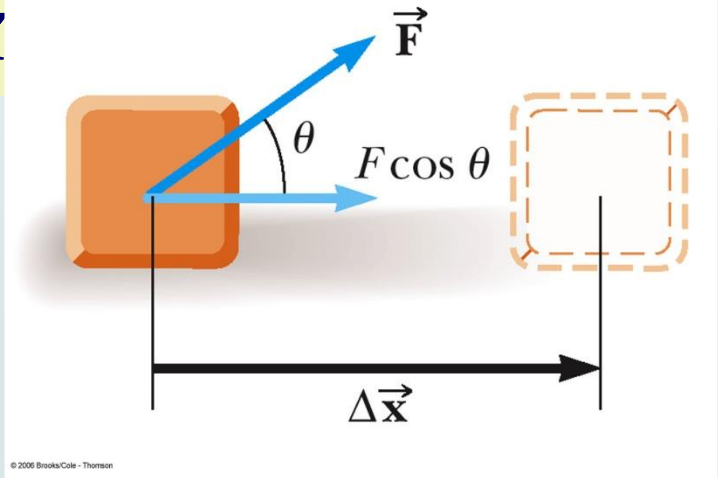
Work W

- Start with $$\frac{1}{2}mv^2 - \frac{1}{2}mv_0^{\ 2} = F_x\Delta x$$ → Work "W"
- Work provides a link between force and energy
- Work done on an object is transferred to/from it
- If W > 0, energy added: "transferred to the object"
- If W < 0, energy taken away: "transferred from the object"

Definition of Work W

- The work, *W*, done with a constant force on an object is defined as the product of the force component in the displacement direction and the magnitude of displacement

$$W \equiv (F\cos\theta)\Delta x = \vec{F}\cdot\Delta\vec{x}$$



- F is the magnitude of the force
- Δ x is the magnitude of the
- object's displacement
- θ is the angle between $\vec{\mathbf{F}}$ and $\Delta\vec{\mathbf{x}}$

Work Unit

- no information about
  - time taken for displacement to take place
  - Velocity or acceleration of an object
- Work is a scalar quantity
- SI Unit
  - Newton • meter = Joule
    - N • m = J
    - J = kg • m^2 / s^2 = (kg • m / s^2) • m

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = (F\cos\theta)\Delta x$$

Figure 7.2
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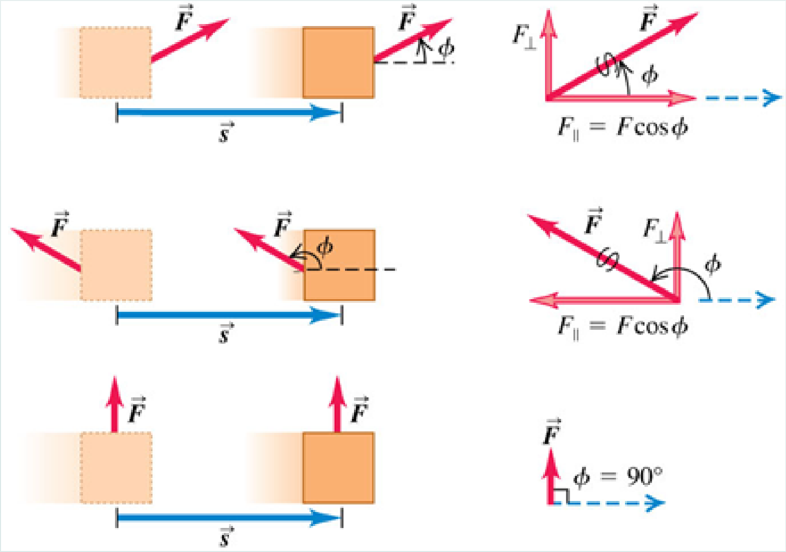
Work: + or -?

- Work can be positive, negative, or zero. Work can be positive, negative or zero. The sign of the work depends on the direction of the force according to the displacement

$$W \equiv (F\cos\theta)x = \vec{F}\cdot\vec{x}$$



- Work positive: if $90° > \theta > 0°$
- Work negative: if $180° > \theta > 90°$
- Work zero: $W = 0$ if $\theta = 90°$
- Work maximum if $\theta = 0°$
- Work minimum if $\theta = 180°$

Example: Work Can Be Positive or Negative

- Work is positive when lifting the box
- Work would be negative if lowering the box
  - The force would still be upward, but the displacement would be downward

Figure 7.3
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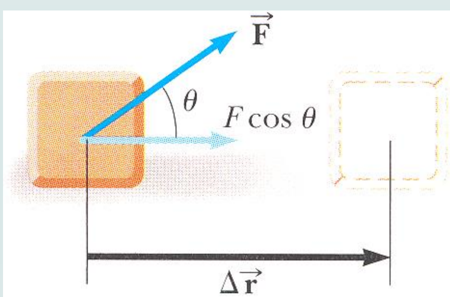
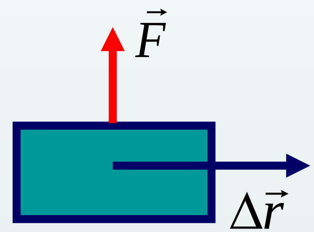
Work Done by a Constant Force

- The work W is performed by an agent that applies a constant force on the system, the magnitude F of the force, the magnitude of the displacement Δr and cos θ of the force application point; where, between the force vector and the displacement vector, θ:

$$W \equiv \vec{F} \cdot \Delta\vec{r} = F\Delta r \cos\theta$$



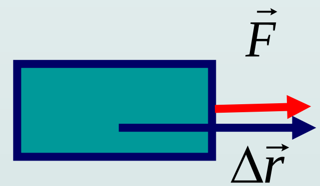


I

$$W_I = 0$$

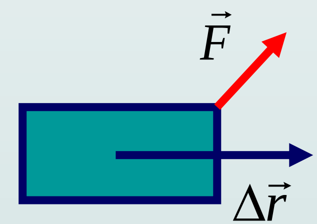
II

$$W_{II} = -F\Delta r$$



III

$$W_{III} = F\Delta r$$



IV

$$W_{IV} = F\Delta r \cos\theta$$

Work and Force

- An man returning pulls a sledge. The total mass of the sled is 50.0 kg, and he exerts a force of 2.40×10^2 N on the sled by pulling on the rope. How much work does he do on the sled if θ = 30° and he pulls the sled 5.0 m ?

$$W = (F\cos\theta)\Delta x$$

$$= (2.40 \times 10^2 N)(\cos 30^\circ)(5.0m)$$

$$= 10.4 \times 10^2 J$$

Work Done by Multiple Forces

- If you apply more than one force to an object, the total work equals the algebraic sum of the work done by the individual forces

$$W_{\text{net}} = \sum W_{\text{by individual forces}}$$

  - Work is a scalar, so this is the algebraic sum

Figure 7.3
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$$W_{net} = W_g + W_N + W_F = (F\cos\theta)\Delta r$$

Kinetic Energy

- Kinetic energy associated with the motion of an object

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

- Scalar quantity with the same unit as work
- Work is related to kinetic energy

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = F_{net}\Delta x$$

$$W_{net} = K_f - K_i = \Delta K$$

Special case: Constant Acceleration

Remember result eliminating t:

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