PHYSICS FOR ENGINEERING I

(PHYS 1210)

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Course Contents

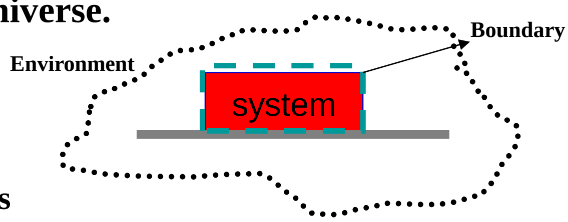
Chapter 7:

Energy and Energy Transfer

Energy Concept

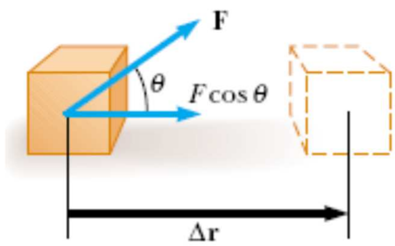
- ✓ **Most important concept in science and engineering.**
- ✓ **Fuel for transport, heating, electricity, food .**
- ✓ **Newton's laws enables us of solving many problems, however, yet there is a wide range of problems that can not be solved easily using such laws.**
- ✓ **When the force acting on object is not constant (hence the net acceleration).**
- ✓ **The previous approach is called particle approach, while the approach developed here is a system approach.**

Systems and Environment



- **The system is a small portion of the Universe.**
- **A valid system:**
  - **may be a single object or particle**
  - **may be a collection of objects or particles**
  - **may be a region of space (such as the interior of an automobile engine combustion cylinder)**
  - **may vary with time in size and shape (such as a rubber ball, which deforms upon striking a wall).**
- **Any system has an imaginary boundary that divides the universe to System (inside the boundary) and environment (outside the boundary).**

Work Done By a Constant Force

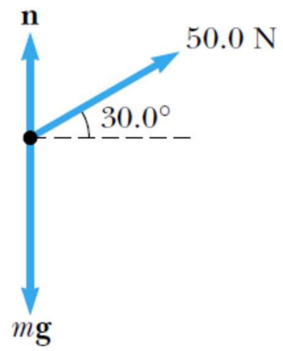


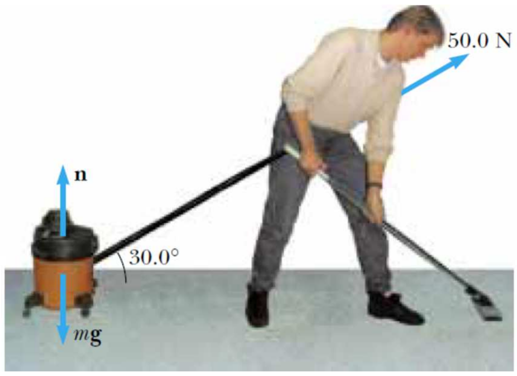
The **work** W done on a system by an agent exerting a constant force on the system is the product of the magnitude F of the force, the magnitude Δr of the displacement of the point of application of the force, and $\cos\theta$, where θ is the angle between the force and displacement vectors:

$$W \equiv F\,\Delta r \cos\theta \qquad (7.1)$$

Example:

A man cleaning a floor pulls a vacuum cleaner with a force of magnitude F= 50.0 N at an angle of 30.0° with the horizontal (Fig. …). Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced 3.00 m to the right.





$$W = F\,\Delta r\cos\theta = (50.0\text{ N})(3.00\text{ m})(\cos 30.0°)$$

$$= 130\text{ N}\cdot\text{m} = 130\text{ J}$$

Work done by a variable force

We cannot evaluate the work by using $W = F\,\Delta r\cos\theta$

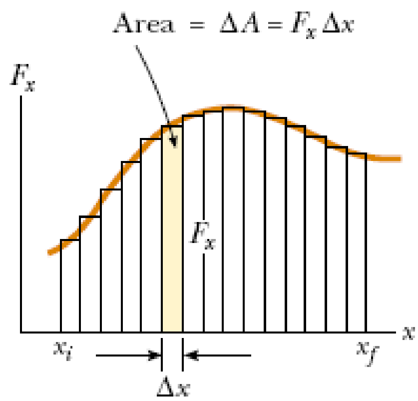
Because the force F is not constant during the displacement Δr.

Consider a very small displacement Δx, It can be assumed safely that the force can be approximated as a constant value during the small displacement, the work for this small displacement is

$$W \approx F_x\,\Delta x$$

we can divide xi to xf displacement to small displacements as shown in the figure, To find the total work take the summation

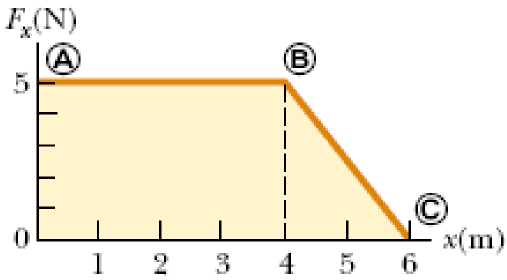
$$W \approx \sum_{x_i}^{x_f} F_x\,\Delta x \qquad \lim_{\Delta x\to 0}\sum_{x_i}^{x_f} F_x\,\Delta x = \int_{x_i}^{x_f} F_x\,dx \qquad W = \int_{x_i}^{x_f} F_x\,dx$$



Important note: *the force and the displacement are in the same direction here (all in the positive x direction)*

Example

A force acting on a particle varies with x, as shown in Figure 7.8. Calculate the work done by the force as the particle moves from $x = 0$ to $x = 6.0$ m.



Solution

$$W = \int_{x_i}^{x_f} F_x \, dx$$

Or the work = area under the F_x graph

= area of the rectangle and triangle

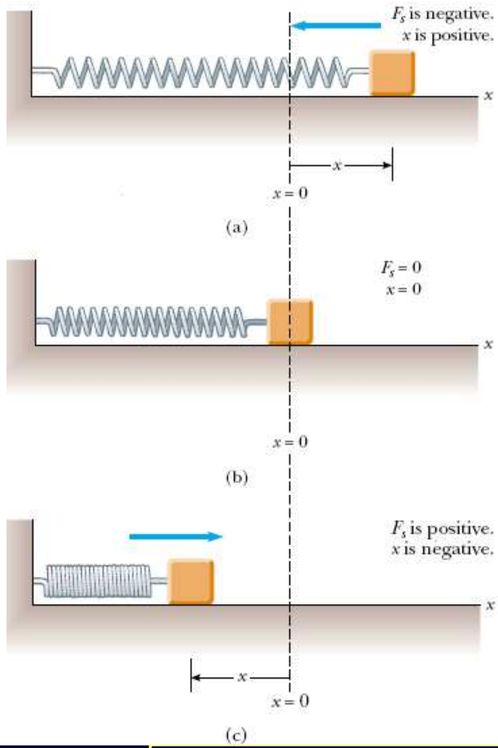
= 5 x 4 + 0.5 x 5 x 2

= 25 J

Work done by a spring

Common example for a force varies with position

$$F_s = -kx$$



Consider the work done by a spring from

$x_i = -x_{max}$ to $x_f = 0$

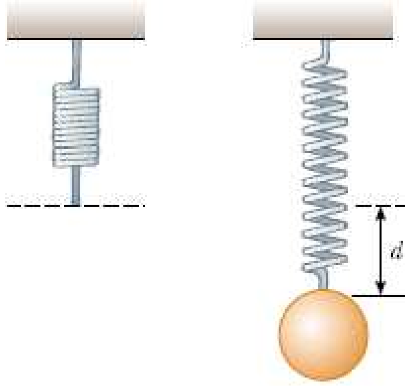
$$W_s = \int_{x_i}^{x_f} F_s dx = \int_{-x_{max}}^{0} (-kx)\, dx = \frac{1}{2} k x_{max}^2$$

And generally the work done by the spring experience a displacement from x_i to x_f

$$W_s = \int_{x_i}^{x_f} (-kx)\, dx = \frac{1}{2} k x_i^2 - \frac{1}{2} k x_f^2$$

Example

A common technique used to measure the force constant of a spring is demonstrated by the setup in Figure 7.12. The spring is hung vertically, and an object of mass m is attached to its lower end. Under the action of the "load" mg, the spring stretches a distance d from its equilibrium position.



(A) If a spring is stretched 2.0 cm by a suspended object having a mass of 0.55 kg, what is the force constant of the spring?

(B) How much work is done by the spring as it stretches through this distance?

Solution

$$k = \frac{mg}{d} = \frac{(0.55\ \text{kg})(9.80\ \text{m/s}^2)}{2.0 \times 10^{-2}\ \text{m}} = 2.7 \times 10^2\ \text{N/m}$$

$$W_s = 0 - \tfrac{1}{2}kd^2 = -\tfrac{1}{2}(2.7 \times 10^2\ \text{N/m})(2.0 \times 10^{-2}\ \text{m})^2$$

$$= -5.4 \times 10^{-2}\ \text{J}$$

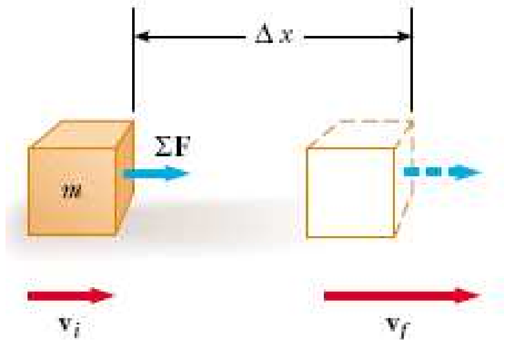
Kinetic Energy and Work-Kinetic Energy Theorem

When doing work, the speed of an object could change

$$\Delta \mathbf{r} = \Delta x \hat{\mathbf{i}} = (x_f - x_i)\hat{\mathbf{i}}$$

$$\sum W = \int_{x_i}^{x_f} \left(\sum F\right) dx$$

Net force



$$\sum W = \int_{x_i}^{x_f} ma\,dx = \int_{x_i}^{x_f} m\frac{dv}{dt}\,dx = \int_{x_i}^{x_f} m\frac{dv}{dx}\frac{dx}{dt}\,dx = \int_{v_i}^{v_f} mv\,dv$$

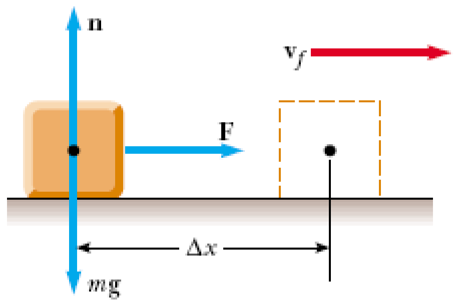
$$\sum W = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2$$

The kinetic energy (K) is defined as:

$$K \equiv \tfrac{1}{2}mv^2 \qquad \sum W = K_f - K_i = \Delta K$$

Example

A 6.0-kg block initially at rest is pulled to the right along a horizontal, frictionless surface by a constant horizontal force of 12 N. Find the speed of the block after it has moved 3.0 m.



Solution

$$W = F\Delta x = (12\,\text{N})(3.0\,\text{m}) = 36\,\text{J}$$

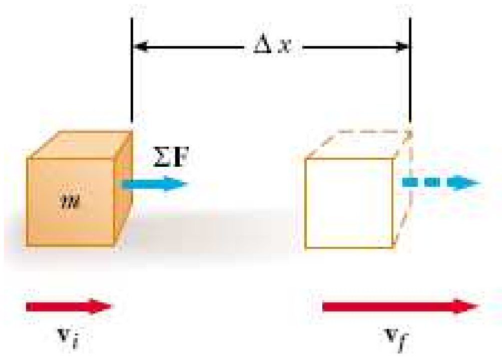
$$W = K_f - K_i = \tfrac{1}{2}mv_f^2 - 0$$

$$v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2(36\,\text{J})}{6.0\,\text{kg}}} = 3.5\,\text{m/s}$$

Power

Power is the time rate of energy transferred (work).

The average power is $\overline{\mathcal{P}} \equiv \dfrac{W}{\Delta t}$



And the instantaneous power is

$$\mathcal{P} \equiv \lim_{\Delta t \to 0} \frac{W}{\Delta t} = \frac{dW}{dt}$$

$$\mathcal{P} = \frac{dW}{dt} = \mathbf{F} \cdot \frac{d\mathbf{r}}{dt} = \mathbf{F} \cdot \mathbf{v}$$

The unit of power is Watt, sometimes horsepower (hp) is used

1 hp = 746 W

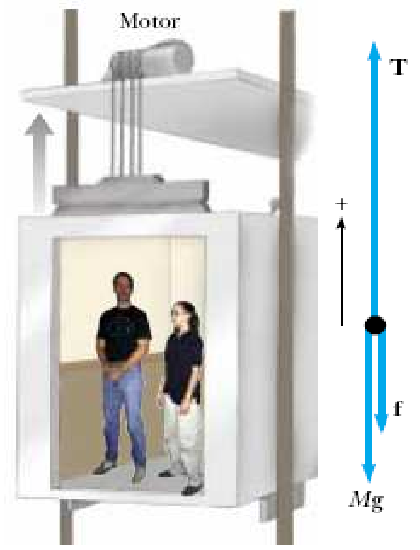
kWh is a unit of energy = 1000 x 3600 J = 3.6 x 10^6 J

Example

An elevator car has a mass of 1 600 kg and is carrying passengers having a combined mass of 200 kg. A constant friction force of 4 000 N retards its motion upward, as shown in Figure 7.19a.

(A) What power delivered by the motor is required to lift the elevator car at a constant speed of 3.00 m/s?

(B) What power must the motor deliver at the instant the speed of the elevator is v if the motor is designed to provide the elevator car with an upward acceleration of 1.00 m/s^2?



Solution

$$\sum F_y = T - f - Mg = 0$$

$$T = f + Mg$$

$$= 4.00 \times 10^3\,\text{N} + (1.80 \times 10^3\,\text{kg})(9.80\,\text{m/s}^2)$$

$$= 2.16 \times 10^4\,\text{N}$$

$$\mathcal{P} = \mathbf{T} \cdot \mathbf{v} = Tv$$

$$= (2.16 \times 10^4\,\text{N})(3.00\,\text{m/s}) = 6.48 \times 10^4\,\text{W}$$

$$\sum F_y = T - f - Mg = Ma$$

$$T = M(a + g) + f$$

$$= (1.80 \times 10^3\,\text{kg})(1.00\,\text{m/s}^2 + 9.80\,\text{m/s}^2) + 4.00 \times 10^3\,\text{N}$$

$$= 2.34 \times 10^4\,\text{N}$$

$$\mathcal{P} = Tv = (2.34 \times 10^4\,\text{N})v$$

$$\mathcal{P} = (2.34 \times 10^4\,\text{N})(3.00\,\text{m/s}) = 7.02 \times 10^4\,\text{W}$$