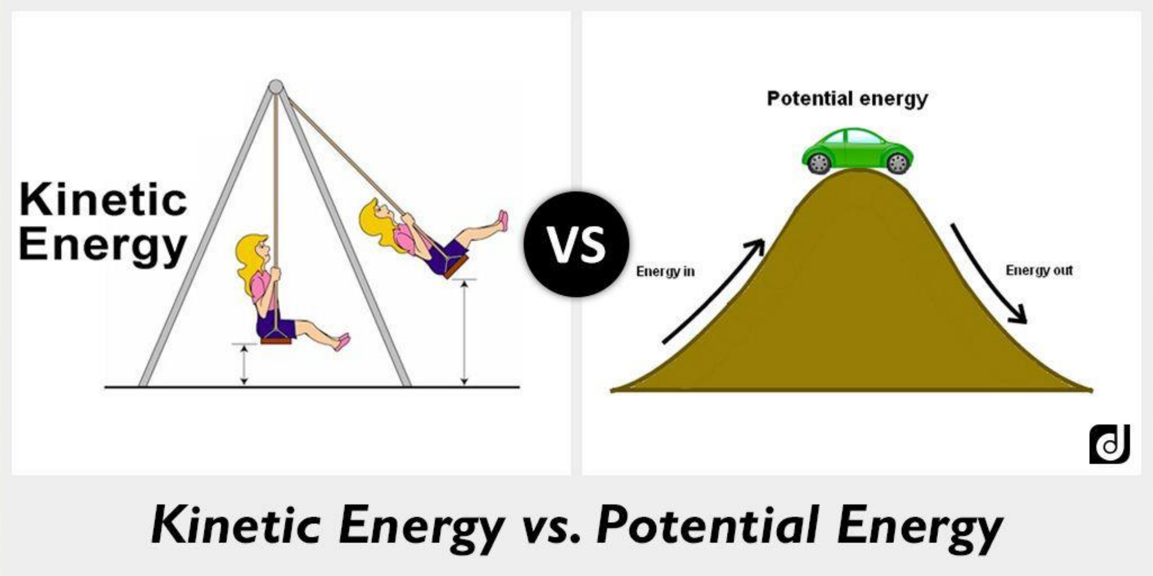
Forms of Energy

1. Potential energy = the *energy* that is stored in an object due to its position relative to some zero position.
2. Kinetic energy = the energy a body has because it is moving.



PE ≡ $-\int_0^r F(r)dr$ and KE ≡ $\frac{1}{2}MV^2$

E ≡ KE + PE = constant (principle of conservation of energy)

3. Internal energy = U = sum of the energy of atoms and molecules

4. Chemical Energy = new molecular species formed = E_{chem}
5. Nuclear Energy = formation of new atomic nuclei = E_{nuc}
6. Electric Energy = electric dipole moment = E_{el}
7. Magnetic Energy = magnetic dipole moment = E_{mag}

Total energy of a material body

$$E \equiv KE + PE + U + E_{chem} + E_{nuc} + E_{el} + E_{mag}$$

In any practical process only a few of these terms are significant.

Three Fundamental Forces

- Gravitational
- Electromagnetic
- Nuclear

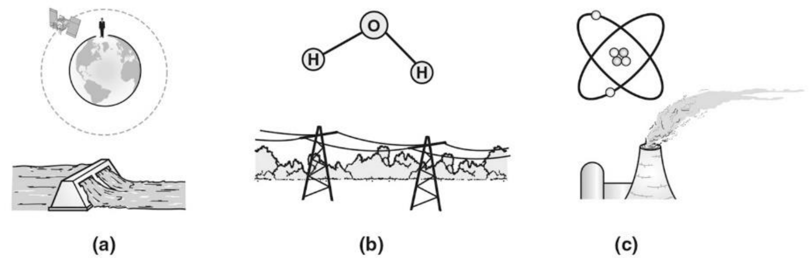
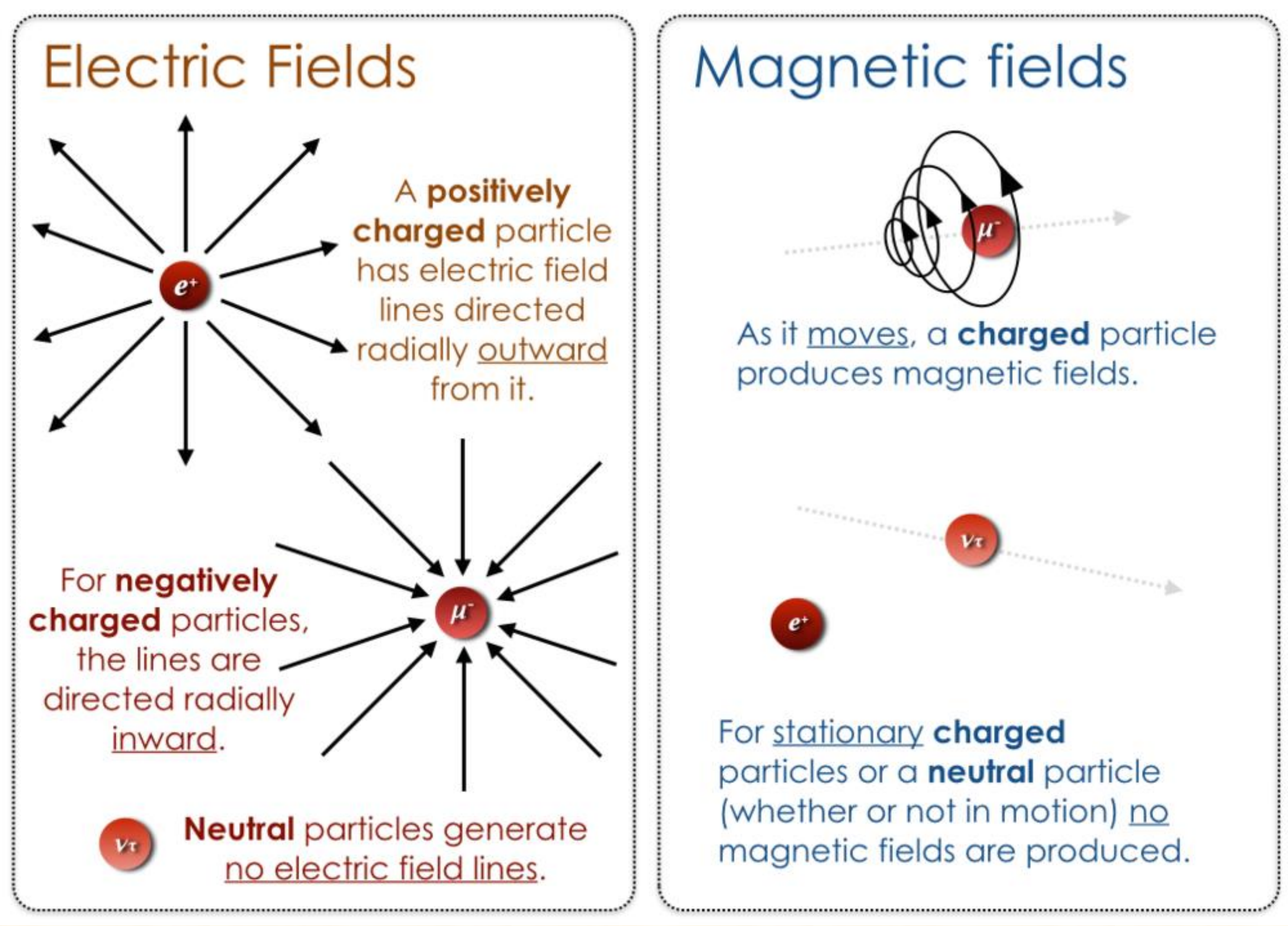


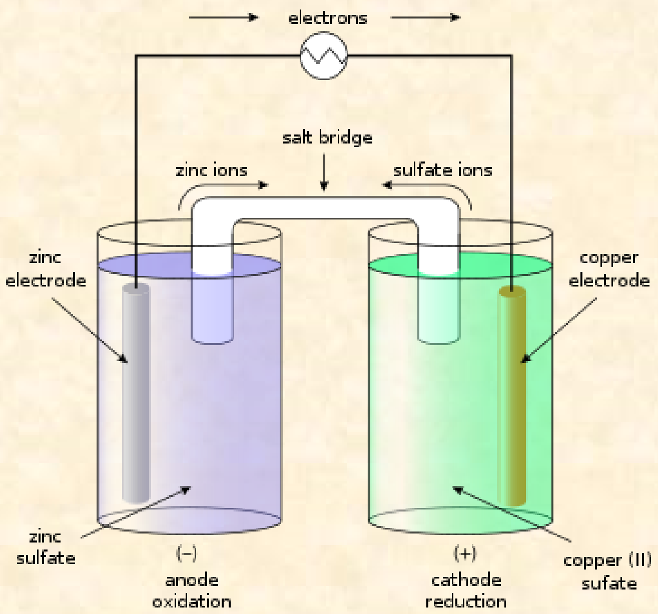
FIGURE 3.2

The fundamental forces and some applications relevant to this book. (a) Gravity governs the large-scale structure of the Universe. It holds you to Earth and keeps a satellite in orbit. Gravitational potential energy is the energy source for hydroelectric power plants. (b) The electromagnetic force is responsible for the structure of matter at the molecular level; the associated potential energy is released in chemical reactions such as those that occur in burning fuels. Electromagnetism is also involved in the production and transmission of electrical energy. (c) The nuclear force binds protons and neutrons to make atomic nuclei. The associated potential energy is the energy source for nuclear power plants.

Electric and Magnetic Fields

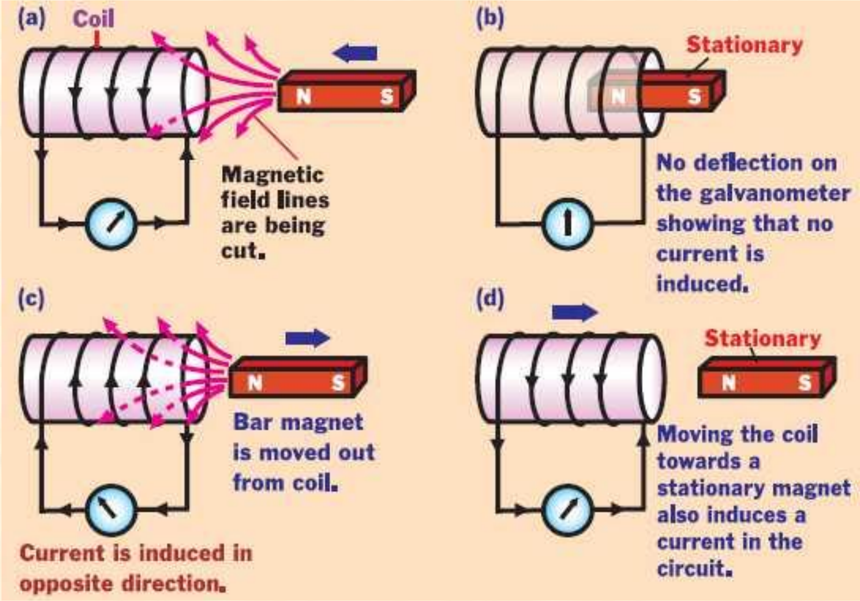


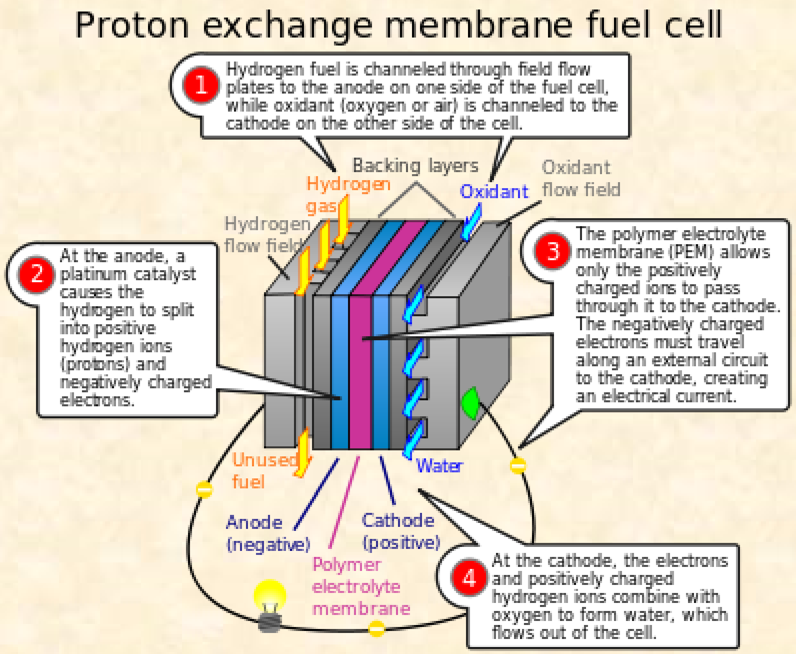
Making Electricity



Electromotive cell (battery) – chemical reaction which results in the transfer of electrons.

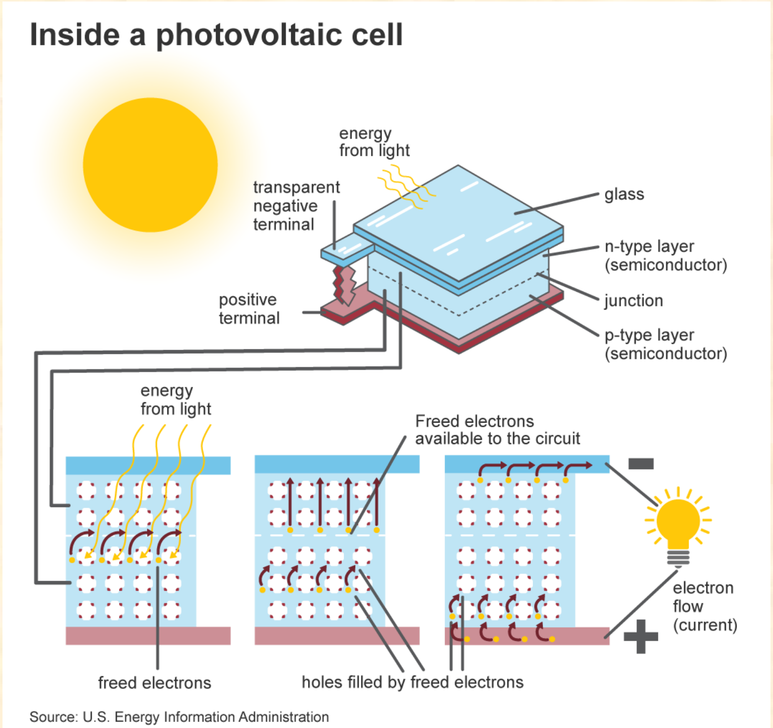
Electromagnetic induction - production of an electromotive force (i.e., voltage) across an electrical conductor in a changing magnetic field.

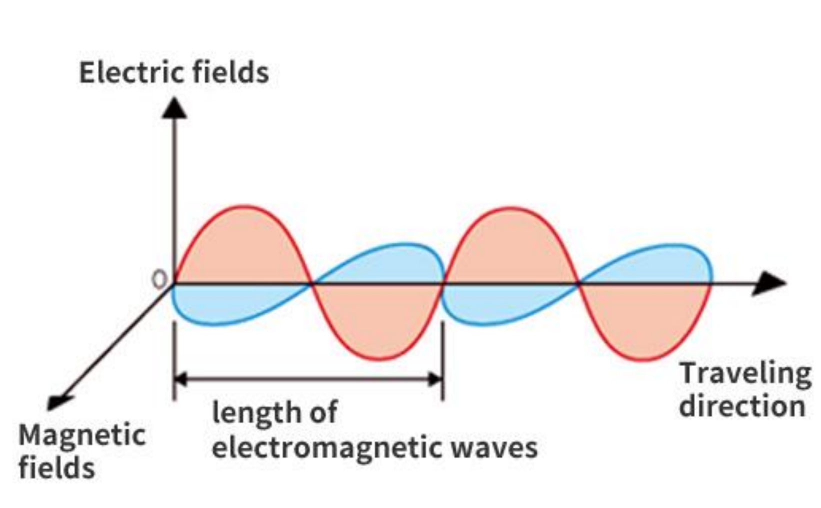




Fuel cell - an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions.

Photovoltaic cell – light photons knock electrons free from atoms resulting in the flow of electrons.





Energy of a photon

We can measure the energy of a photon using Einstein's equation:

$$E = hf = \frac{hc}{\lambda}$$

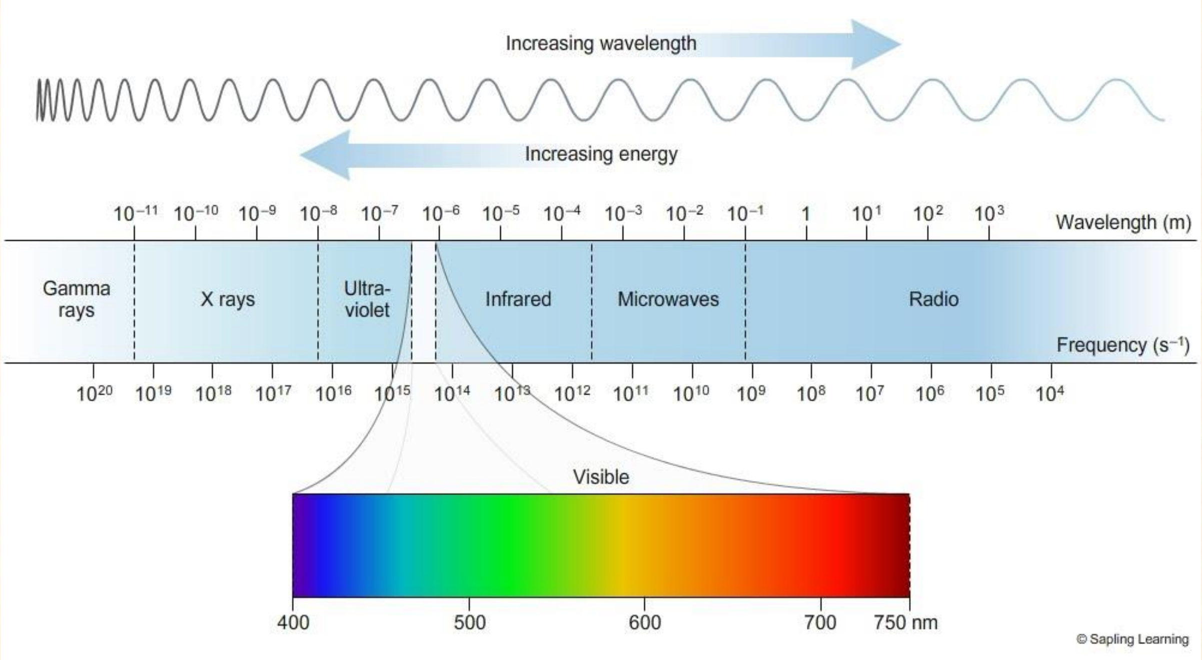
$h = 6.63 \times 10^{-34}$ Js → Planck constant

f = frequency of photon/electromagnetic radiation

$c = 3 \times 10^{8}$ m/s → speed of light in a vacuum

λ = wavelength of photon/electromagnetic radiation

Electromagnetic energy and the wave – particle duality of light



Quantifying Energy

TABLE 3.1 | ENERGY AND POWER UNITS

Energy unit	Joule equivalent*	Description
joule (J)	1 J	Official SI energy unit; equivalent to 1 W·s or the energy involved in applying a force of 1 newton over a distance of 1 meter
kilowatt-hour (kWh)	3.6 MJ	Energy associated with 1 kW used for 1 hour (1 MJ = 10^6 J)
gigawatt-year	31.6 PJ	Energy produced by a typical large (1 gigawatt) power plant operating full-time for 1 year (1 PJ = 10^{15} J)
calorie (cal)	4.184 J	Energy needed to raise the temperature of 1 gram of water by 1°C
British thermal unit (Btu)	1,054 J	Energy needed to raise the temperature of 1 pound of water by 1°F, very roughly equal to 1 kJ
quad (Q)	1.054 EJ	Quad stands for quadrillion Btu, or 10^{15} Btu; 1 Q is roughly equal to 1 exajoule (10^{18} J)
erg	10^{-7} J	Energy unit in the centimeter-gram-second system of units
electron volt (eV)	1.6×10^{-19} J	Energy gained by an electron dropping through an electric potential difference of 1 volt; used in atomic and nuclear physics
foot-pound	1.356 J	Energy unit in the English system, equal to the energy involved in applying a force of 1 pound over a distance of 1 foot
tonne oil equivalent (toe)	41.9 GJ	Energy content of 1 metric ton (1,000 kg, roughly 1 English ton) of oil (1 GJ = 10^9 J)
barrel of oil equivalent (boe)	6.12 GJ	Energy content of one 42-gallon barrel of oil
Power unit	**Watt equivalent**	**Description**
watt (W)	1 W	Equivalent to 1 J/s
horsepower (hp)	746 W	Unit derived originally from power supplied by horses; now used primarily to describe engines and motors
Btu per hour (Btu/h, or Btuh)	0.293 W	Used primarily in the United States, usually to describe heating and cooling systems.

*See Table 3.2 for SI prefixes.

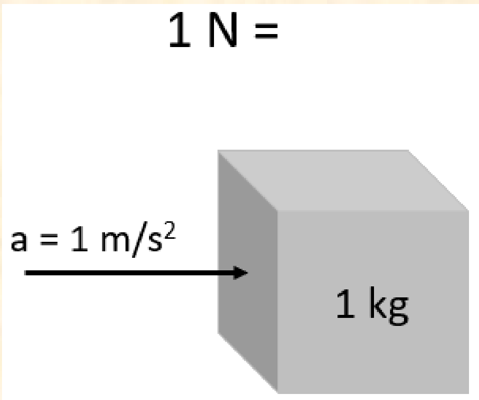
TABLE 3.3 | ENERGY CONTENT OF FUELS

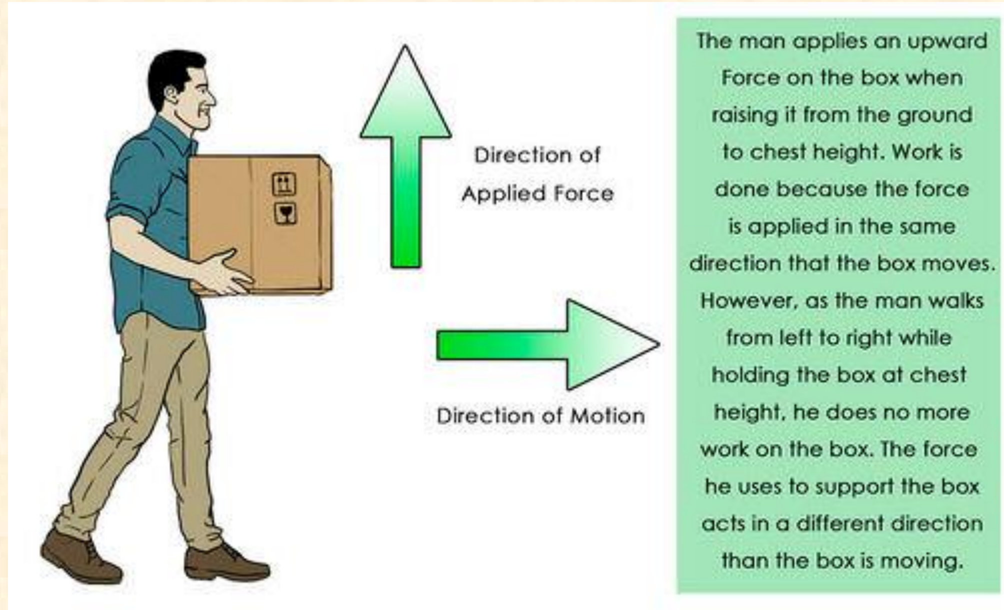
	Typical energy content (varies with fuel source)	
Fuel	**SI units**	**Other units**
Coal	29 MJ/kg	7,300 kWh/ton 25 MBtu/ton
Oil	43 MJ/kg	~40 kWh/gallon 138 kBtu/gallon
Gasoline	44 MJ/kg	36 kWh/gallon
Natural gas	55 MJ/kg	30 kWh/100 cubic feet 1,000 Btu/cubic foot
Biomass, dry	15–20 MJ/kg	13–17 MBtu/ton
Hydrogen gas (H_2) burned to produce H_2O	142 MJ/kg	320 Btu/cubic foot
Uranium, nuclear fission:		
Natural uranium	580 GJ/kg	161 GWh/tonne
Pure U-235	82 TJ/kg	22.8 TWh/tonne
Hydrogen, deuterium–deuterium nuclear fusion:		
Pure deuterium	330 TJ/kg	
Normal water	12 GJ/kg	13 MWh/gallon, 350 gallons gasoline equivalent per gallon water

Newton's First Law – a body in motion tends to remain in motion in a straight line unless acted upon by an unbalanced force.

Force = mass x acceleration

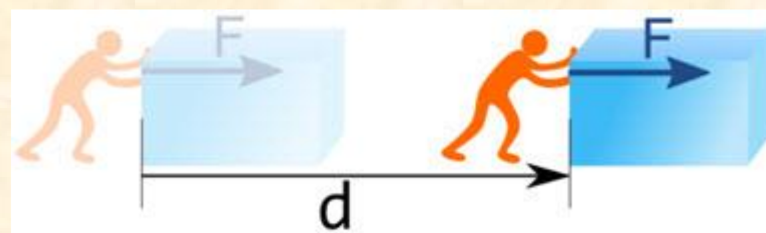
SI Unit → Newton





Work = force x distance

Joule = force of 1 Nt applied over a distance of 1 m.

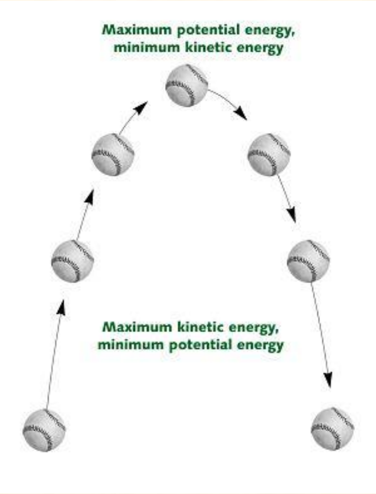


Work and Kinetic Energy

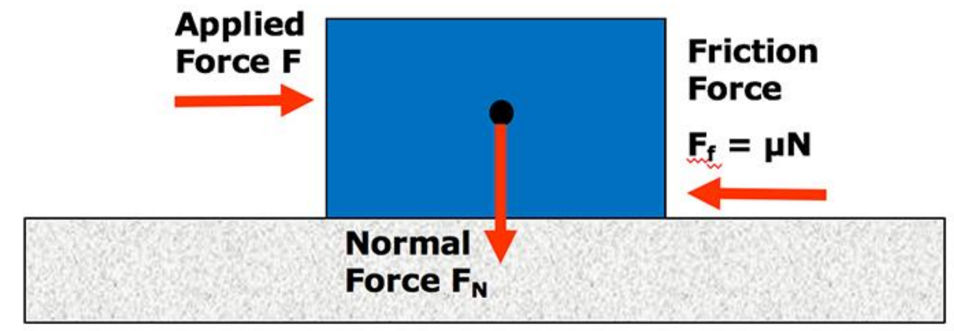
Work-energy theorem - the **work** done by the sum of all forces acting on a particle equals the change in the kinetic **energy** of the particle.

Kinetic Energy = ½ mass x velocity^2

Potential energy (mgh) versus kinetic energy.



Friction - the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.



μ = coefficient of friction