

Dimensions of the energy concept

Energy cannot be defined in a short statement. But just as with the Newtonian concept of “force,” energy can be defined in terms of all the different statements we can make about it. The meaning of the term “energy” is distributed across all these statements. A sample of these statements follows.

1) Energy is a *function* of certain variables that determine the *state* of some physical object or system, and it may be considered to be stored within that physical object or system.

a) The energy stored within a physical object or system can be quantified on some definite scale.

i) Within moving objects due to translation: $E_{C.M.} = \frac{1}{2}mv_{C.M.}^2$

ii) Within moving objects due to rotation about C.M.: $E_{rotating\ object} = \frac{1}{2}I_{C.M.}\omega^2$

iii) Within ideal gases: $E_{gas} = \frac{3}{2}NkT$

iv) Within gravitational fields: $E_{grav} = mgy$ or $E_{gravitation} = -G\frac{m_1m_2}{r}$

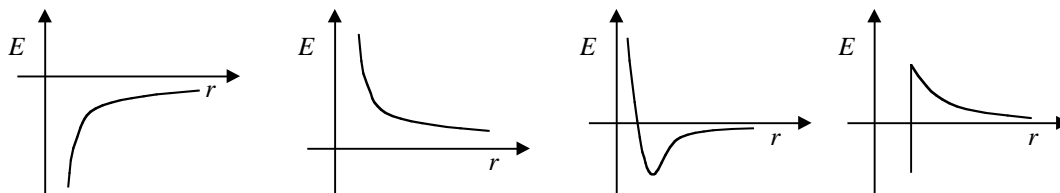
v) Within electric fields: $E_{electric\ field} = \int \frac{1}{2}\epsilon_0|\mathbf{E}|^2 dV$

vi) Within magnetic fields: $E_{magnetic\ field} = \int \frac{1}{2\mu_0}|\mathbf{B}|^2 dV$

vii) Within photons: $E = h\nu$

viii) Within ideal springs: $E_{spring} = \frac{1}{2}k\Delta l^2$

ix) Within the field through which two particles interact:



b) When the quantity of energy stored within an object or system changes, some feature of the object or system itself changes.

c) The quantity of energy stored in an object or system, E , is dependent on the reference frame specified.

d) The quantity of energy stored in an object or system is equal to the arithmetic sum of the energy stored in each of its parts. $E_{total} = \sum_i E_i$

e) Energy stored in a physical object or system at rest has mass $m = \frac{E}{c^2}$.

2) Energy can be transferred from one physical object or system to another.

a) Two objects or systems may be considered to be separate if the energy transferred between them is much larger than the energy stored due to their mutual interaction.

b) Energy can be transferred from one part to another *within* a physical object or system. There is no formal name for such transfers.

c) Energy can be transferred *between* specified *systems* of physical objects.

i) Energy can be transferred because of a difference in temperature between two systems by collisions on the microscopic scale (accompanied by an entropy transfer): Heating, Q

(1) $\Delta E = mc\Delta T$

(2) $\Delta E = nH_f$

(3) $\Delta E = nH_v$

(4) Energy spontaneously flows from an object at a higher temperature to an object at a lower temperature.

- (5) The rate of energy flow from one object to another depends on
- (a) The difference in temperature
 - (b) The amount of contact between the systems
 - (c) The means of energy transport (conduction, radiation, convection)
- ii) Energy can be transferred by a well-defined force exerted either by or on a system (accompanied by a momentum transfer): Working,, $W = \int \mathbf{F} \cdot d\vec{\ell}$
- iii) Energy can be transferred by electromagnetic radiation (accompanied by an entropy transfer): Radiation, R
- iv) Energy can be transferred by matter, μN , where μ is the chemical (or Gibbs) potential and N is the number of moles of substance.
- d) The amount of energy exchanged between objects is independent of the reference frame specified.
- i) $\Delta E_{1 \text{ kinetic}} + \Delta E_{2 \text{ kinetic}} = \Delta E'_{1 \text{ kinetic}} + \Delta E'_{2 \text{ kinetic}}$
 - ii) $mg\Delta y = mg\Delta y'$
- e) For a physical object or system at rest the transfer of an amount of energy ΔE results in a change in mass $\Delta m = \frac{\Delta E}{c^2}$.
- f) The rate at which energy is transferred may be thought of as an energy current.
- i) The rate of energy transfer through “working” is called “power.”
 - ii) The rate of energy transfer by other means has no special name.
 - iii) The rate of energy transfer via electromagnetic fields is given by the outward normal component of the Poynting vector, $\frac{1}{\mu} \mathbf{E} \times \mathbf{B}$, integrated over a closed surface.
- 3) The amount of energy in the universe is constant. Energy cannot be made, nor can it be destroyed.
- a) For an open system: $\Delta E_{total} = Q + W + R + \mu N = \sum_i \Delta E_i$
 - b) For a closed system $Q = W = R = \mu N = 0$: $\Delta E_{total} = 0 = \sum_i \Delta E_i$
- 4) Energy tends to disperse to more and more objects. Entropy can be made, but it cannot be destroyed.
- a) When a system exchanges an amount of energy ΔE it also exchanges an amount of entropy $\Delta S_{input} = \frac{\Delta E}{T}$
 - b) The addition of energy to a system increases the number of states that it may have unless this energy is transferred to it while maintaining quasistatic equilibrium. Irreversible processes create entropy.
 - c) When the temperature of a system increases entropy is created. $\Delta S_{created} = \frac{T_2 - T_1}{T_1} \Delta S_{input}$