General bound object:

$$\text{Mass} = \frac{\text{Total Energy at Rest}}{c^2} = \text{constituent particle masses} + \underbrace{\frac{\text{particle kinetic energies}}{c^2} + \frac{\text{potential energy}}{c^2}}_{\text{Binding energy}}$$

can be −ve

negative for stable bound system.

$\therefore M < M_{constituents}$.

Useful relation:

$$\boxed{E^2 = p^2c^2 + m^2c^4}$$

(check: plug in $E = \gamma mc^2$, $\vec{p} = \gamma m\vec{v}$)

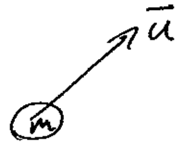
→ general relation between mass, energy, & momentum in relativity.

- $m = 0$ gives $E = |\vec{p}|c$
- Can have finite energy for $m \to 0$ if $v \to c$

⟷ Same properties as electromagnetic waves!

NEXT WEEK: light is made of massless particles with $v = c$.

LAST TIME:



Momentum: $\vec{p} = \gamma m \vec{u}$

Energy: $E = \gamma m c^2$

Conserved in all processes.

$$E = \gamma m c^2 \rightarrow \underbrace{mc^2}_{\text{MASS ENERGY}} + \underbrace{(\gamma - 1) mc^2}_{\text{KINETIC ENERGY}}$$

not separately conserved

Q: What is mass?

A: $\boxed{\text{Mass} = \text{total energy of an object at rest} \times \frac{1}{c^2}}$

CLICKER:

e.g. Heating an object $\longrightarrow$ kinetic energy of atoms increases $\longrightarrow$ mass increases!

another e.g.:

H atom = stable bound system $\Longrightarrow$ Need to add energy to separate constituents

E conservation:

$$\underset{M_H c^2}{\text{Energy of H atom}} + E_{added} = \underset{M_p c^2 + M_e c^2}{\text{Energy of separated constituents}}$$

$$\therefore M_H < M_p + M_e$$

Carbon 12 $\longrightarrow$ 6 protons + 6 neutrons + 6 electrons

mass 12 amu

$$6m_p + 6m_e + 6M_n = 12.099 \text{ amu}$$