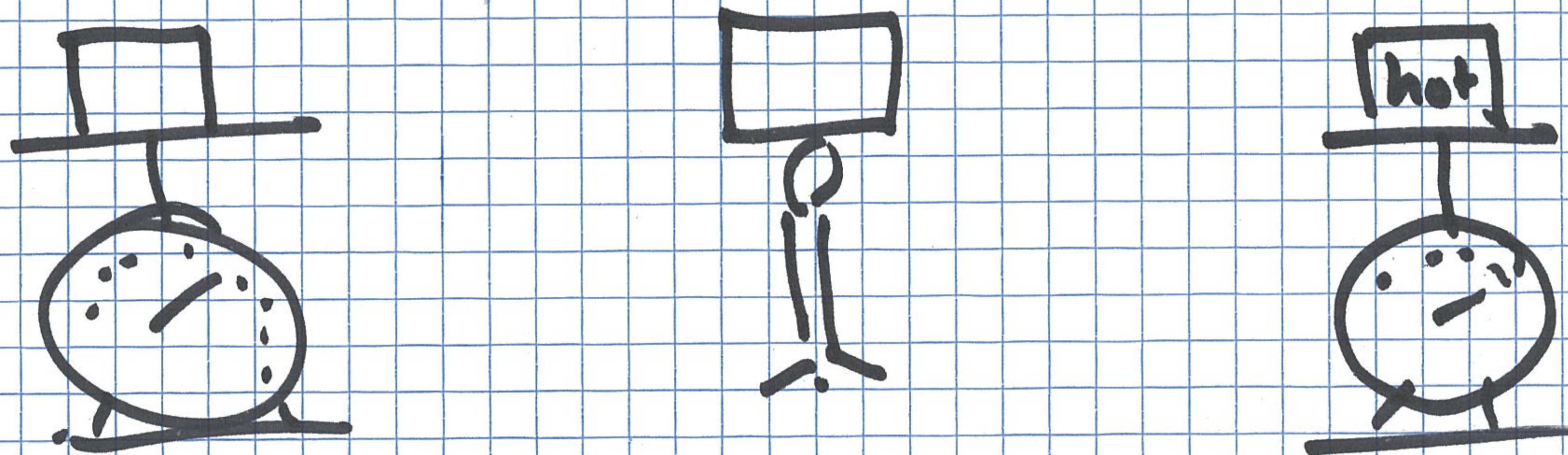
NYU Physics I 2017-12-14.

- final exam
- Qs
- $E = mc^2$

Noether's theorem



chemical bonds: ~ eV

mass of H ~ GeV

LHC: $\gamma \sim 10^4$

Lab

before

$$\vec{p}\left(\frac{E}{c}, p_x, 0, 0\right)$$

$$= (\gamma m c, \gamma m v, 0, 0)$$

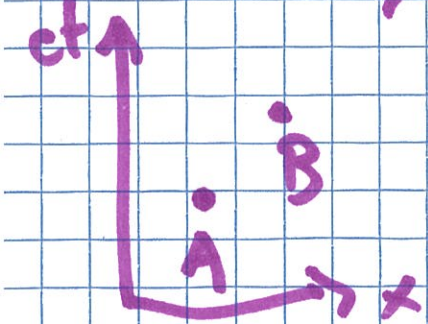
$$\vec{p}\cdot\vec{p} = \gamma^2 m^2 c^2 - \gamma^2 m^2 v^2$$

$$= \gamma^2 m^2 (c^2 - v^2)$$

$$= \gamma^2 m^2 c^2 (1-\beta^2)$$

$$= m^2 c^2 \frac{(1-\beta^2)}{(1-\beta^2)}$$

$$= m^2 c^2$$



$$\vec{\Delta s} = (c\Delta t, \Delta x, \Delta y, \Delta z)$$

$$|\vec{\Delta s}|^2 = (c\Delta t)^2 - \Delta x^2 - \Delta y^2 - \Delta z^2$$

$$\vec{\Delta s}\cdot\vec{\Delta s}$$

RepL

$\underset{m}{\bullet}$

$$\vec{p} = \left(\frac{E}{c}, 0, 0, 0\right)$$
$$= (mc, 0, 0, 0)$$
$$\vec{p}\cdot\vec{p} = m^2c^2$$

what if $m = 0$ $\qquad p_x = \gamma m v_x$

$$\cancel{\vec{p} = (\gamma mc, \gamma mv, 0, 0)}$$

$$\vec{p} = \left(\frac{E}{c}, p_x, 0, 0\right) \qquad \vec{p}\cdot\vec{p} = \frac{E^2}{c^2} - p_x^2 \overset{?}{=} 0 \text{ ??}$$

If you have $m \equiv 0$, the $\frac{E}{c} = p$

$$\vec{P} = \left(\frac{E}{c}, p_x, p_y, p_z\right)$$

$$\vec{P}\cdot\vec{P} = \frac{E^2}{c^2} - \underbrace{p_x^2 - p_y^2 - p_z^2} = m^2c^2$$

$$\frac{E^2}{c^2} - |\vec{p}|^2 = m^2c^2$$

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

if $\vec{p} = \vec{0}$, $\underline{E = mc^2}$

$(1+\epsilon)^n = 1 + n\epsilon + \dots$

@ small $\frac{v^2}{c^2}$: $\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$

$$\gamma = 1 + \frac{1}{2}\frac{v^2}{c^2}$$

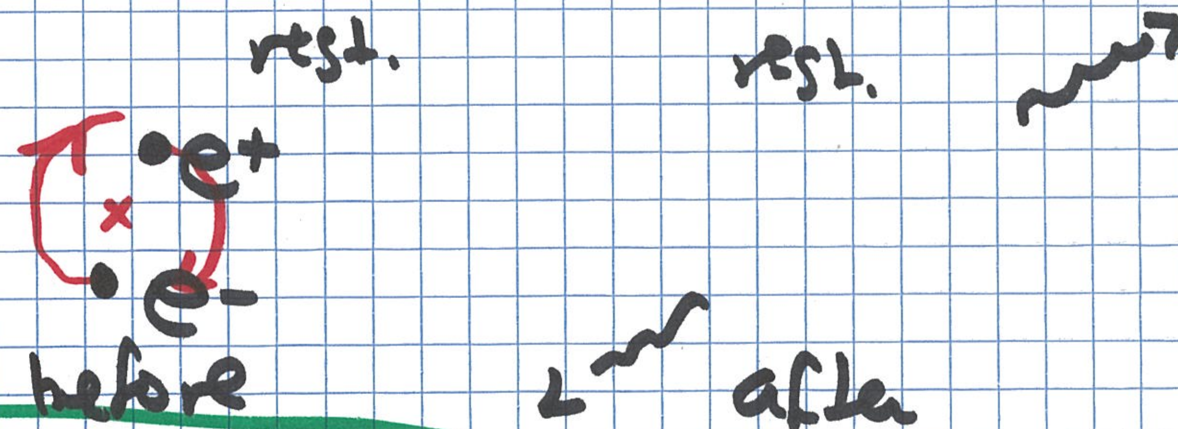
$$p_t \equiv \gamma m c = \frac{E}{c}$$

$$E = \gamma m c^2 = \left(1 + \frac{1}{2}\frac{v^2}{c^2}\right) m c^2$$

$$= mc^2 + \frac{1}{2} m v^2$$

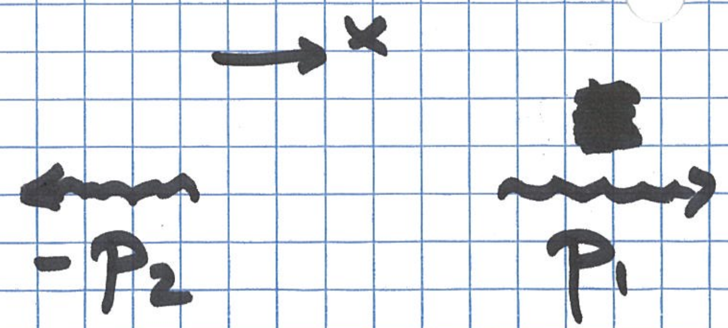
$$\boxed{KE \equiv \gamma m c^2 - m c^2}$$

positronium



$$\boxed{m_{positronium} = 2 \cdot m_e - \frac{E_b}{c^2}}$$

Lab
after



$|p_1| > |p_2|$!

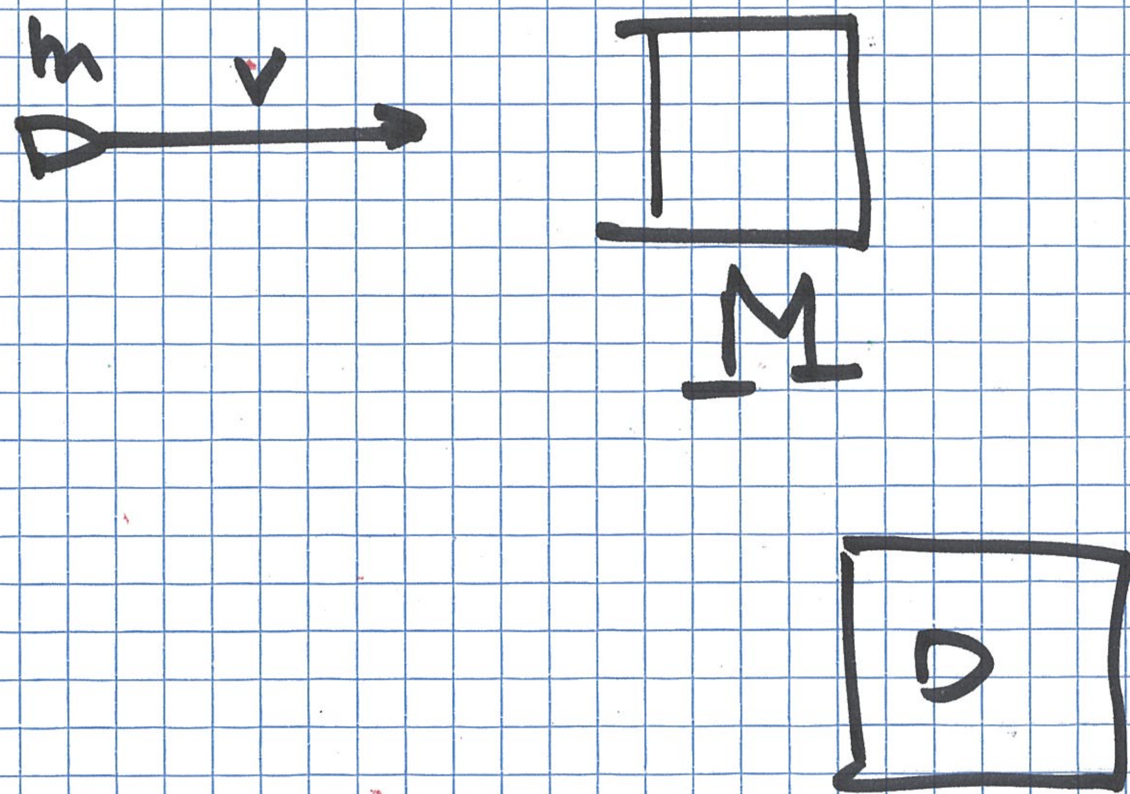
Photons: $E = h\nu$ photons can have different energies.

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

4-momentum:

$$\left.\begin{aligned} \overset{4}{\vec{P}} &= (p_1, p_1, 0, 0) \\ &+ (p_2, -p_2, 0, 0) \\ \hline &(p_1 + p_2, p_1 - p_2, 0, 0) \end{aligned}\right\} \text{handles } \overset{3}{\vec{P}} \text{ cons. \& E cons.}$$

$$= (\gamma mc, \gamma mv, 0, 0)$$



$\cancel{M' = M + m}$??