Chapter 10: Wrapping up Special Relativity

Energy, (relativistic) mass vs. rest mass

$E = m c^2$ & applications

Triggered by questions after class last Tu:

Review of the γ factor - $T = \gamma T_0$ $L = L_0/\gamma$ $m = \gamma m_0$

Revisiting biological clocks, aging, time travel, etc.

And now, what is it with **$E = m c^2$**, perhaps the most famous equation in all of physics?
A deep idea, of crucial importance, very well confirmed & tested (experimentally), but also subtle & prone to mis-interpretations.
Hopefully you read 10.8 carefully…….

→ Ultimately it implies that E and m go hand in hand, are synonymous, *all E has m, and all m has E*! A surprising prediction of special relativity, no doubt.

→ Since E is (always!) conserved, m is (always!) conserved.
But: that does ***not*** imply that m_0 is necessarily conserved – matter can be destroyed or created!
Tons of examples (again) in subatomic particle physics:
$e^- + e^+ \rightarrow 2\gamma$ ("pair annihilation" – matter destroyed!)
γ (+ matter, i.e. in a detector) $\rightarrow e^- + e^+$ ("pair creation" – matter created, detection of high-E gammas)

→Careful with the word "mass"! **Distinguish m (inertia) from m_0 (rest mass, amount of matter, atoms) !**

Interesting consequences: $m(C) + m(O_2)$ ←→ $m(CO_2)$?

For example, $C + O_2 \rightarrow CO_2 + E_{thermal}$ clearly implies that CO_2 has ***less*** mass than $m_C + m_{O2}$, the difference being called the "*bindingenergy*" of CO_2. A tiny amount relative to their rest masses!

By the same token, the H atom (= $p + e^-$) has ***less*** mass than the sum $m_p + m_e$, again by a very small amount, but easily measurable.

On the other hand, in *nuclear* processes, these "mass differences" are ***not*** tiny at all! That's the fuel of stars like our sun……

(Time permitting:

a) "Einstein's Box" Gedankenexperiment;

b) $E_{total} = E_{kin} + E_0$ for a particle, ignoring other possible forms of E)

Note the interesting comments at the very end of ch. 10 on the modern view of the importance of *fields/forces/interactions*.

In particular that some of a composite object's mass must be due to internal force fields – fields that bind the constituents together. Extreme example: protons/neutrons and their constituents, the so-called "quarks" – explain……

CONCEPT CHECK 11 In which of the following processes does the system's mass change? (a) A bullet that speeds up while moving down a gun barrel. (b) A rubber band that is being stretched around a package. (c) Two positively charged objects that are moved closer to each other and placed at rest. (d) An electron and an antielectron, at rest, that spontaneously annihilate each other.

<u>C.E. 46 - 48</u>

Quiz # 88: In the pair annihilation process $e^- + e^+ \rightarrow 2\gamma$ is energy conserved? Is mass conserved? Is rest-mass conserved?

(a) Yes Yes No

(b) Yes Yes Yes

(c) Yes No No

(d) Yes No Yes

(e) No Yes No

Problem 7: $m = E / c^2 = 90 \text{ J} / 9 \times 10^{16} \text{ m}^2/\text{s}^2 = 10^{-15} \text{ kg}$ (!)

→Please make sure you can follow the solution of problem 11.

Quiz # 89: Consider two mousetraps that are identical except that one of them is set, and the other not.

(a) The two have exactly the same mass.

(b) The one that is set is ever so slightly more massive.

(c) The one that is not set is ever so slightly more massive.

(d) None of the above.

Quiz # 90: Relative to you an electron moves with 99% of c, at which speed the relativistic γ factor is 7. Let's compare the electron's rest energy E_0 with its total energy E:

(a) $E = 7 E_0$, and difference between the two energies is $E_{kinetic}$.
(b) $E = E_0$, and therefore the difference is zero.
(c) $E = 7 E_0$, and the difference is $E_{thermal}$.
(d) $E_0 = 7 E$, and the difference is $E_{kinetic}$.
(e) $E = 7 E_0$, and the difference is nuclear energy.

Let's do Problem 8, 1 GW nuclear power plant, how much mass converted into E in one day? A: ~1 g(ram)

Quiz # 91: You might recall that a proton is about 2000 times as massive (in terms of rest mass, of course!) as an electron. How fast must an e^- travel to appear as massive as a proton at rest?

(a) About 86% of c. (b) About 50% of c. (c) Impossible.
(d) Extremely relativistic, >99% of c. (e) About 20% of c.