Physics 205 Test 3

I pledge that I have neither given nor received unauthorized assistance during the completion of this work.

Name ______________________ Signature ______________________

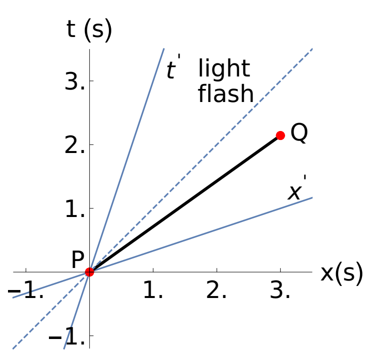
Questions (7 for 7 pts. apiece) Answer in complete, well-written sentences WITHIN the spaces provided.

1. If the momentum of a particle going close to the speed of light doubles does the velocity double? Explain.

2. If you move from one bright fringe in a double-slit interference pattern to the next one out from the central maximum, does the path length difference δ increase, decrease, or stay the same? If it changes, by how much in terms of wavelength λ? Explain.

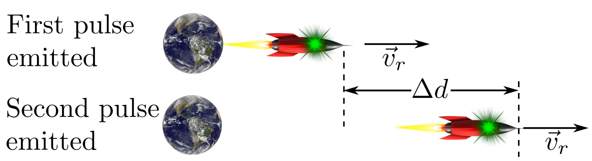
3. A system consists of two photons moving in opposite directions, one with energy E and the other with energy $4E$. What is the system's total mass? Explain.

4. The figure below shows a two-observer, spacetime diagram. It is claimed that the points P and Q are causally connected. Is that true or false? Explain.

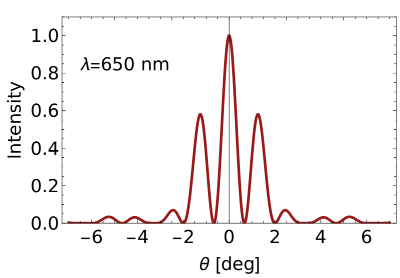


5. A sealed cup of water is placed inside a microwave oven. The water absorbs microwave energy which causes its atoms to vibrate more vigorously making the water warmer. What happens to the mass of the water in the cup? Explain.

6. Answer this question non-relativistically. An observer on the (roughly) stationary Earth watches a spaceship traveling away and towards the galactic core at a speed v_r. The craft emits a burst of light from a beacon that is later observed by the Earthbound observer. After a proper time interval Δt_{rocket} as measured by the captain of the spaceship, another burst of light is emitted. A schematic drawing of the two events is shown below. The ship travels a proper distance Δd between pulses as measured by the Earthbound observer. How long is the time interval between light pulses as measured by the Earthbound observer in terms of v_r, Δt_{rocket}, and Δd?



7. From the figure below how would you determine the size of the slits and their separation in a double slit experiment? You should use the plot to define the numerical inputs to your calculation, but don't actually do any calculations.



Problems (4). Clearly show all reasoning for full credit. Use a separate sheet for your work.

1. 8 pts. A particle has 4-momentum $\underset{\sim}{p} = [p_t, p_x, p_y, p_z] = [5\ kg, 0, 3\ kg, 0]$ in SR units. What is the particle's mass?

2. 12 pts. A spaceship, at rest in the reference frame S, is given a speed increment of $0.5c$. Relative to its new rest frame it is given a further $0.5c$ increment. This process is continued until its speed with respect to its original frame S exceeds $0.96c$. How many increments does this process require?

3. 15 pts. When a high-power laser is used in the Earths atmosphere, the electric field can ionize the air, turning it into a conducting plasma that reflects the laser light. In dry air at 0° C and 1 atm, electric breakdown occurs for fields with amplitudes above about $2.0 \times 10^5\ V/m$. (a) What average laser beam intensity will produce such a field? (b) At this maximum intensity, what power can be delivered in a cylindrical beam of diameter 4.0 mm? (c) What is the size of the magnetic field?

4. 16 pts. A particle of mass m decays into two identical particles that move in opposite directions, each with a speed of $\frac{12}{13}c$. What is the mass of each of the product particles expressed as a fraction of m?

DO NOT WRITE BELOW THIS LINE.

Physics 205 Equations

$$\vec{F}_{net} = \sum \vec{F}_i = m\vec{a} = \frac{d\vec{p}}{dt} \quad v = \frac{dx}{dt} \quad v = \frac{\Delta x}{\Delta t} \quad x = \frac{1}{2}at^2 + v_0 t + x_0 \quad v = at + v_0 \quad a_g = -g \quad a_c = \frac{v^2}{r}$$

$$\vec{F}_{Earth} = -mg\hat{\jmath} \quad KE = \frac{1}{2}mv^2 \quad KE_0 + PE_0 = KE_1 + PE_1 \quad PE_{Earth} = mgh \quad PE_V = qV$$

$$\vec{p}_i = \vec{p}_f \quad \vec{p} = m\vec{v} \quad \vec{F}_C = k_e \frac{q_1 q_2}{r^2}\hat{r} \quad \vec{E} \equiv \frac{\vec{F}}{q_0} \quad d\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{dq}{r^2}\hat{r}$$

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{s} \times \hat{r}}{r^2} = \frac{\mu_0}{4\pi}\frac{qd\vec{v} \times \hat{r}}{r^2} \qquad \vec{F}_B = q\vec{v} \times \vec{B} \qquad |\vec{F}_B| = |qvB\sin\theta|$$

Galilean Transformation SI units	Lorentz Transformation SI units	Lorentz Transformation SR units
$x' = x - vt$	$x' = \gamma(x - vt)$	$x' = \gamma(x - \beta t)$
$y' = y$	$y' = y$	$y' = y$
$z' = z$	$z' = z$	$z' = z$
$t' = t$	$t' = \gamma(t - vx/c^2)$	$t' = \gamma(t - \beta x)$
$v'_x = v_x - v_O$	$v'_x = \frac{v_x - v_O}{1 - v_x v/c^2}$	$v'_x = \frac{v_x - \beta}{1 - v_x \beta}$

Coordinate Time	Proper Time	Spacetime Interval
Time between two events in an inertial frame measured with synchronized clocks	Time between two events measured by the same clock at both events.	Time between two events measured by the same, inertial clock at both events.
$c\Delta t$,Δt	$\Delta\tau_{SI}$, $\Delta\tau_{SR}$	Δs_{SI}, Δs_{SR}
Frame dependent	Frame independent	Frame independent

$$\Delta s_{SI}^2 = c^2\Delta t^2 - \Delta d^2 = {\Delta s'_{SI}}^2 \quad \text{or} \quad \Delta s_{SR}^2 = \Delta t^2 - \Delta d^2 = {\Delta s'_{SR}}^2$$

$$\Delta\tau_{SI} = \int_{t_A}^{t_B} \sqrt{1 - \frac{v^2}{c^2}}\, dt \quad \text{or} \quad \Delta\tau_{SR} = \int_{t_A}^{t_B} \sqrt{1 - \beta^2}\, dt$$

$$\Delta\tau_{SI} = \sqrt{1 - v^2/c^2}\ \Delta t \quad \text{or} \quad \Delta\tau_{SR} = \sqrt{1 - \beta^2}\ \Delta t$$

$$L_{SI} = L_R\sqrt{1 - v^2/c^2} \quad \text{or} \quad L_{SR} = L_R\sqrt{1 - \beta^2}$$

$$v'_x = \frac{v_x - v}{1 - v_x v/c^2} \quad v'_y = \frac{v_y\sqrt{1 - v_x^2/c^2}}{1 - v_x v/c^2} \quad KE = E - mc^2 \quad \text{SI units}$$

$$v'_x = \frac{v_x - \beta}{1 - v_x \beta} \quad v'_y = \frac{v_y\sqrt{1 - \beta^2}}{1 - v_x \beta} \quad KE = E - m \quad \text{SR units}$$

$$\underset{\sim}{p}_i = \underset{\sim}{p}_f \quad \underset{\sim}{p}_1 \cdot \underset{\sim}{p}_2 = \underset{\sim}{p}_3 \cdot \underset{\sim}{p}_4$$

$$\underset{\sim}{p} = m\, d\underset{\sim}{s}/d\tau = [m\frac{dt}{d\tau}, m\frac{dx}{d\tau}, m\frac{dy}{d\tau}, m\frac{dz}{d\tau}] = \frac{m}{\sqrt{1 - |\vec{v}|^2}}[1, \vec{v}] \quad \underset{\sim}{p} \cdot \underset{\sim}{p} = E_r^2 - |\vec{p}|^2 = m^2 \qquad \text{SR units}$$

$$\underset{\sim}{p} = m\, d\underset{\sim}{s}/d\tau = [mc\frac{dt}{d\tau}, m\frac{dx}{d\tau}, m\frac{dy}{d\tau}, m\frac{dz}{d\tau}] = \frac{m}{\sqrt{1 - v^2/c^2}}[c, \vec{v}] \quad \underset{\sim}{p}c \cdot \underset{\sim}{p}c = E_r^2 - |\vec{p}c|^2 = (mc^2)^2 \qquad \text{SI units}$$

$$y = A\sin(kx - \omega t + \phi) \quad k\lambda = \omega T = 2\pi \quad E = E_m \sin(kx - \omega t + \phi) \quad B = B_m \sin(kx - \omega t + \phi) \quad \phi = k\delta$$

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \quad E = cB \quad \langle|\vec{S}|\rangle = I = \frac{E^2}{2\mu_0 c} = \frac{\text{energy}}{\text{area} \cdot \text{time}} \quad c = \frac{\lambda}{T} = \lambda f$$

$$\delta = d\sin\theta = m\lambda \ (m = 0, \pm 1, \pm 2, ...) \quad \delta = a\sin\theta = m\lambda \ (m = \pm 1, \pm 2, ...) \quad \phi = k\delta$$

$$I_{int} = I_m \cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right) \quad I_{diff} = I_m \left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2 \quad I_{total} = I_m \cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right)\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2$$

$$\frac{d}{dx}(f(u)) = \frac{df}{du}\frac{du}{dx} \quad \int x^n dx = \frac{x^{n+1}}{n+1} \quad \int \frac{1}{x}dx = \ln x \quad \vec{A}\cdot\vec{B} = AB\cos\theta \quad |\vec{A}\times\vec{B}| = |AB\sin\theta|$$

$$\frac{d}{dx}(x^n) = nx^{n-1} \quad \frac{de^x}{dx} = e^x \quad \frac{d}{dx}(\ln x) = \frac{1}{x} \quad \frac{d}{dx}(\cos ax) = -a\sin ax \quad \frac{d}{dx}(\sin ax) = a\cos ax$$

$$\langle x\rangle = \frac{1}{N}\sum_i x_i \quad \sigma = \sqrt{\frac{\sum_i (x_i - \langle x\rangle)^2}{N-1}} \quad C = 2\pi r \quad A = 4\pi r^2 \quad V = Ah \quad V = \frac{4}{3}\pi r^3$$

$$\frac{df(x)}{dx} = \lim_{\Delta x\to 0}\frac{f(x+\Delta x) - f(x)}{\Delta x} \quad \int_a^b f(x)dx = \lim_{\Delta x\to 0}\sum_{n=1}^{N} f(x)\Delta x$$

$$\int \frac{1}{x}dx = \ln x \quad \int x^n dx = \frac{x^{n+1}}{n+1} \quad \int e^{ax}dx = \frac{e^{ax}}{a} \quad \int \frac{1}{\sqrt{x^2+a^2}}dx = \ln\left[x + \sqrt{x^2+a^2}\right]$$

$$\int \frac{x}{\sqrt{x^2+a^2}}dx = \sqrt{x^2+a^2} \quad \int \frac{x^2}{\sqrt{x^2+a^2}}dx = \frac{1}{2}x\sqrt{x^2+a^2} - \frac{1}{2}a^2 \ln\left[x + \sqrt{x^2+a^2}\right]$$

$$\int \sqrt{1-ax^2}dx = \frac{x}{2}\sqrt{1-ax^2} + \frac{\arcsin\left(\sqrt{a}x\right)}{2\sqrt{a}} \quad \int \frac{x^3}{\sqrt{x^2+a^2}}dx = \frac{1}{3}(-2a^2+x^2)\sqrt{x^2+a^2}$$

Physics 205 Constants and Conversions

Avogadro's number (N_A)	6.022×10^{23}	Speed of light (c)	$3 \times 10^8\ m/s$
k_B	$1.38 \times 10^{-23}\ J/K$	proton/neutron mass	$1.67 \times 10^{-27}\ kg$
1 u	$1.67 \times 10^{-27}\ kg$	g	$9.8\ m/s^2$
Gravitation constant	$6.67 \times 10^{-11}\ N-m^2/kg^2$	Earth's radius	$6.37 \times 10^6\ m$
Coulomb constant (k_e)	$8.99 \times 10^9 \frac{N-m^2}{C^2}$	Electron mass	$9.11 \times 10^{-31}\ kg$
Elementary charge (e)	$1.60 \times 10^{-19}\ C$	Proton/Neutron mass	$1.67 \times 10^{-27}\ kg$
Permittivity constant (ϵ_0)	$8.85 \times 10^{-12} \frac{kg^2}{N-m^2}$	1.0 eV	$1.6 \times 10^{-19}\ J$
1 MeV	$10^6\ eV$	atomic mass unit (u)	$1.66 \times 10^{-27}\ kg$
Planck's constant (h)	$6.63 \times 10^{-34}\ Js$	Planck's constant (h)	$4.14 \times 10^{-15}\ eVs$
Permeability constant (μ_0)	$1.26 \times 10^{-6}\ Tm/A$	Rydberg constant (R_H)	$1.097 \times 10^7\ m^{-1}$
Becquerel (Bq)	$1\ decay/s$	Curie (Ci)	$3.7 \times 10^{10}\ Bq$