Physics 205 Final

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

Name ______________________ Signature ______________________

Questions (11 for 4 pts. apiece) Answer in complete, well-written sentences WITHIN the spaces provided.

1. Sunlight falling on a spaceship in a vacuum will cause the spaceship to become positively charged. True or false? Explain.

2. An electron moving near a proton can never be unbound. True or False? Explain.

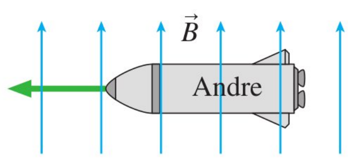
3. Suppose you have a mixed gas of hydrogen and a molecule that behaves like a harmonic oscillator. When we excite these systems and look at their emission spectrum, we see only two visible lines whose wavelengths we measure. Our detector has a limited range for measuring wavelengths. Can we determine what kind of system we have? Explain.

4. Can we can use a numerical method on a computer to calculate a solution to Schrödinger's equation for a bound quanton or quantum particle with any energy? Explain.

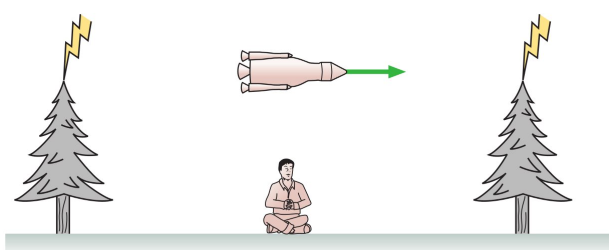
DO NOT WRITE BELOW THIS LINE.

5. A spacecraft zooms past the Earth at constant velocity. An observer on Earth measures a clock on the spacecraft is ticking at one-third the rate as an identical clock on the Earth. What does an observer see on the spacecraft for the Earth-based clocks ticking rate? Explain.

6. Andre is flying his spaceship to the left through the laboratory magnetic field of the figure below. (a) Does Andre see a magnetic field? If so, in which direction does it point? (b) Does Andre see an electric field? If so, in which direction does it point? Explain your answers.



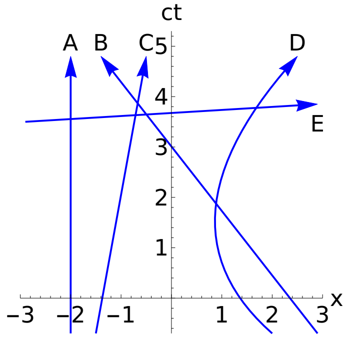
7. The figure shows a rocket traveling from left to right. At the instant it is halfway between two trees, lightning simultaneously (in the rocket's frame) hits both trees. A student was sitting on the ground halfway between the trees as the rocket passed overhead. According to the student, were the lightning strikes simultaneous? If not, which tree was hit first? Explain.



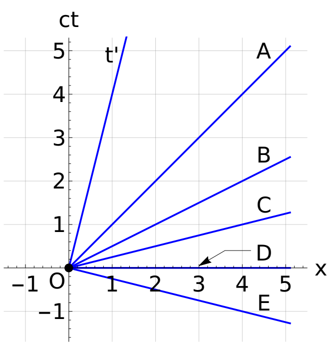
DO NOT WRITE BELOW THIS LINE.

8. A system consists of two photons moving in opposite directions, one with energy $2E$ and the other with energy $5E$. What is the system's total mass? Explain.

9. The spacetime diagram in the figure below shows the worldlines of various objects. Which object has the largest speed at time $t = 1$ s? Explain.

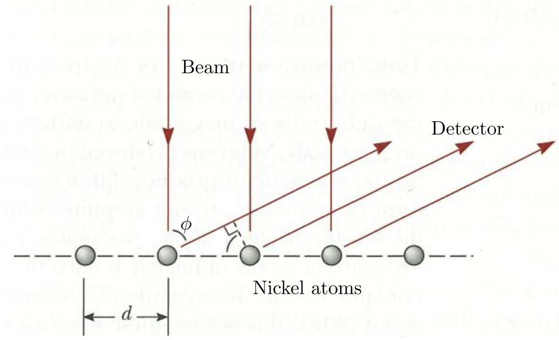


10. In the figure the Other frame is moving in the $+x$ direction with x-velocity $\beta = 1/4$ with respect to the Home frame. The two-observer diagram in the figure shows the diagram t and x axes of the Home frame and the diagram t' axis of the Other frame. Which of the choices in the figure would best correspond to the diagram x' axis? Explain.



DO NOT WRITE BELOW THIS LINE.

11. The figure shows a schematic view of the interaction of electron waves with nickel atoms in a lattice in the Davisson-Germer experiment. Constructive interference occurs when two scattered waves overlap and their path difference is an integer multiple of the electron wavelength. Where is the path difference in the figure? How is it related to the angle ϕ and any other parameters? Explain your reasoning.



Problems (7). Clearly show all reasoning for full credit. Use a separate sheet for your work.

1. 6 pts. A particle has 4-momentum

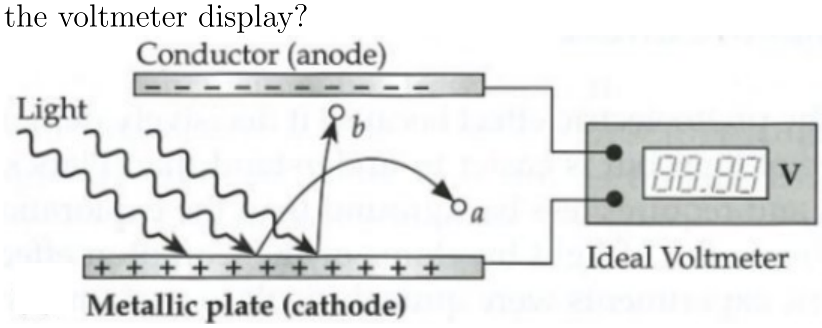
$$\underset{\sim}{p} = [p_t, p_x, p_y, p_z] = [5\ kg, 0, 3\ kg, 0]$$

in SR units. What is the particle's mass?

2. 6 pts. Green light emitted by a laser pointer has a wavelength of about 532 nm. What is the energy of one photon from such a laser?

3. 8 pts. At what speed is a particle's momentum twice its Newtonian value?

4. 8 pts. Suppose you do an experiment with a setup like the one shown in the figure where violet light with a wavelength $\lambda = 430$ nm falls on a cesium cathode whose work function is $W = 2.1$ eV. What value will the voltmeter display?



5. 8 pts. A friend passes by you in a spacecraft traveling at a high speed. He tells you that his craft is $\ell_1 = 20.0\ m$ long and that the identically constructed craft you are sitting in is $\ell_2 = 19.0\ m$ long. According to your observations, (a) how long is your spacecraft, (b) how long is your friends craft, and (c) what is the speed of your friends craft?

6. 10 pts. In the Davisson-Germer experiment what would be the smallest nonzero angle (relative to the direction of the original beam) where reflected electrons might constructively interfere if the kinetic energy of the electrons is $KE = 125$ eV? Is there another possible angle of constructive interference? The separation of the nickel atoms is $d = 0.14\ nm$.

7. 10 pts. An object moves with velocity $v_x' = 2/5$ in SR units in an inertial frame attached to a train which in turn moves with x-velocity $\beta = 4/5$ in the $+x$-direction with respect to the ground. What is the object's velocity v_x with respect to the ground? Evaluate this question with a carefully drawn two-observer spacetime diagram.

Physics 205 Equations

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

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

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

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

$$\vec{E}_B = \vec{E}_A + \vec{v}_{BA} \times \vec{B}_A \quad \vec{B}_B = \vec{B}_A - \mu_0\epsilon_0\vec{v}_{BA} \times \vec{E}_A$$

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

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

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

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

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

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

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

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

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

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

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

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

$$\delta = d\sin\theta = m\lambda \ (m = 0, \pm1, \pm2, ...) \quad \delta = a\sin\theta = m\lambda \ (m = \pm1, \pm2, ...) \quad \phi = k\delta$$

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

$$E = hf \quad KE_{max} = eV_{stop} = hf - W \quad c = \lambda f \quad ME = \frac{p_r^2}{2m} + \frac{L^2}{2mr^2} + V \quad \vec{v} = v_r\hat{r} + v_\theta\hat{\theta} \quad |\vec{L}| = mv_t r$$

$$V_C = \frac{k_e q_1 q_2}{r} \quad V_G = -\frac{Gm_1 m_2}{r} \quad p = \frac{h}{\lambda} \quad E_H = -\frac{13.6\ eV}{n^2} \quad \vec{p}_i = \vec{p}_f \quad \vec{p} = m\vec{v} \quad KE_i = KE_f \text{ (elastic)}$$

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

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

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

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

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

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

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

$$x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$$

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	$1.38 \times 10^{-23}\ J/K$	Elementary charge (e)	$1.60 \times 10^{-19}\ C$
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)	$8.99 \times 10^9 \frac{N-m^2}{C^2}$	Coulomb constant (e^2)	$\hbar c/137$
Proton/Neutron mass	938 MeV/c^{2}g	Proton/Neutron mass	$1.67 \times 10^{-27}\ kg$
Electron mass	$9.11 \times 10^{-31}\ kg$	Electron mass	0.511 MeV/c^2
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)	$4.14 \times 10^{-15}\ eVs$
Planck's constant ($\hbar c$)	197 MeV − fm	Planck's constant ($\hbar c$)	1970 eV − Å
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)	$3.7 \times 10^{10}\ Bq$