Physics 370 Exam 1 Solutions

October 5, 2016

$\boxed{3}$ 1. Explain the difference between inertial and noninertial reference frames.

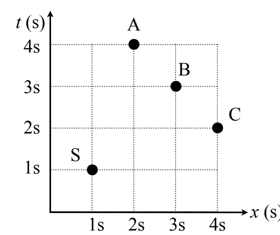
Newton's First Law is valid in inertial frames

$\boxed{3}$ 2. **B** Which runs more slowly?

A) a clock on top of a mountain **B)** a clock at the base of the mountain

C) It depends on where the observer is

3. The graph shows four events, in $c = 1$ units.



$\boxed{3}$ (a) **C** Which event(s) could be simultaneous with S in *some* other frame? (That is, for which event(s) does there exist a frame such that S and that event are simultaneous?)

A) A **B)** B **C)** C **D)** none

E) B and C **F)** A and B **G)** A, B, and C

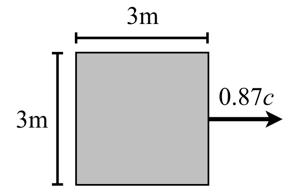
$\boxed{3}$ (b) Find the spacetime interval Δs between events S and A.

$$\Delta s = \sqrt{\Delta t^2 - \Delta x^2} = \sqrt{9-1} = \sqrt{8}\,\mathrm{s} = 2.8\,\mathrm{s}$$

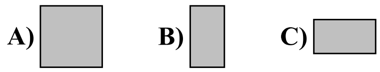
$\boxed{2}$ (c) What is the spacetime interval Δs between events S and A, in a frame that is moving at speed $0.8c$ to the right?

$\Delta s = 2.8\,\mathrm{s}$, the same in all frames

4. A $3\,\mathrm{m} \times 3\,\mathrm{m}$ square (in its frame) is moving at $0.87c$ to the right in the "rest" frame (i.e. the frame of this paper).



$\boxed{3}$ (a) __B__ What does the square look like in the rest frame?



$\boxed{3}$ (b) __B__ What is the (horizontal) length of the square as seen in the rest frame?

A) $1.35\,\mathrm{m}$ **B)** $1.5\,\mathrm{m}$ **C)** $1.7\,\mathrm{m}$ **D)** $3\,\mathrm{m}$ **E)** $6\,\mathrm{m}$

$\gamma = \frac{1}{\sqrt{1-(0.87)^2}} = 2$, so the width is $3\,\mathrm{m}/2 = 1.5\,\mathrm{m}$

5. Passengers in a rocket travel to a distant star. It takes them 18 years to get there from our perspective, travelling at a velocity such that $\gamma = 1.5$.

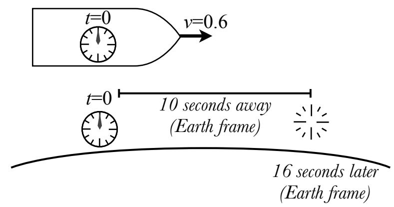
$\boxed{3}$ (a) If event A is the moment the rocket leaves Earth, and event B is the moment the rocket arrives at the star, what is the distance $\Delta x'$ between those events, in the passenger's frame?

Zero: both events occur in the same place in the passenger's frame

$\boxed{3}$ (b) __B__ How long does it take to reach the star, from a passenger's perspective?

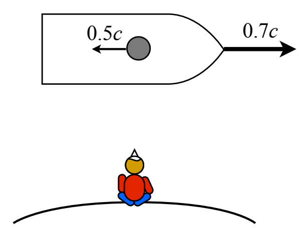
A) 9 years **B)** 12 years **C)** 15 years
D) 18 years **E)** 27 years **F)** 36 years

$\boxed{3}$ 6. When a rocket moving at $0.6c$ in the $+x$ direction flies by an observer on Earth, clocks on the rocket and on Earth both read $t = 0$. According to the Earthly observer, a firecracker goes off 16 s later, at a distance of 10 s away (using $c = 1$ units). When the firecracker goes off, what time does the rocket observer see on her clock?



$$t' = \gamma(t - vx) = 1.25(16 - 0.6(10)) = \boxed{12.5\,\text{s}}$$

$\boxed{3}$ 7. A rocket is travelling by the Earth at $0.7c$ to the right. Someone inside the rocket throws a ball that moves at $0.5c$ to the left, from their perspective. How fast is the ball moving in the Earth's frame, and in which direction?



$$\frac{0.7 - 0.5}{1 - 0.7(0.5)} = +0.3 \text{ which is to the right}$$

$\boxed{3}$ 8. **A** True or false: Massless particles can be deflected by a gravitational field.

$\boxed{4}$ 9. Fill in the blanks in this paragraph:
The ultraviolet catastrophe was the paradox which predicted that a **blackbody** emits **infinite** energy, due to there being too may standing waves with **high** frequency. Planck solved the paradox by assuming that the energy of a given standing wave with frequency f must be **an integer multiple of hf**.

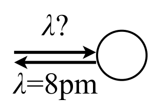
$\boxed{3}$ 10. Explain the difference between the photoelectric effect and bremsstrahlung.
For the photoelectric effect,

photons hit metal and electrons are released

while for bremsstrahlung,

electrons hit metal and photons are created

$\boxed{3}$ 11. **A** A gamma ray hits a stationary electron, and is reflected directly backwards with a wavelength of 8 picometers. What was the wavelength of the original gamma ray? (Note: $h/m_e c = 2.42\,\text{pm}$.)



A) 3.16 pm **B)** 5.58 pm **C)** 8 pm **D)** 10.42 pm **E)** 12.84 pm

$$8 = \lambda + \frac{h}{mc}(1 - \cos\theta) = \lambda + (2.42\,\text{pm})(2)$$

12. Green light (500 nm) shines on metal, and a stream of (nonrelativistic) electrons are detected from the metal moving at 5×10^5 m/s.

$\boxed{3}$ (a) How much energy does each photon of green light possess?

$$hf = h\frac{c}{\lambda} = \frac{(6.626 \times 10^{-34})(3 \times 10^8)}{500 \times 10^{-9}} = 4.0 \times 10^{-19}$$

$\boxed{3}$ (b) How much energy is required to liberate an electron from the surface of this metal?

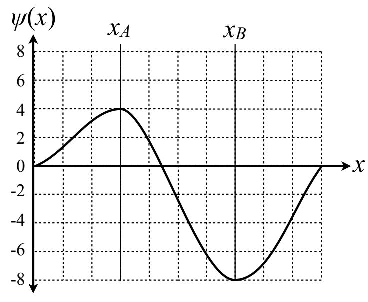
Each electron emerges with kinetic energy $KE = \frac{1}{2}mv^2 = \frac{1}{2}(9.11 \times 10^{-31})(5 \times 10^5)^2 = 1.1 \times 10^{-19}\,\text{J}$. The remaining energy from each photon is needed to liberate the electron; that is, $\phi = 4.0 \times 10^{-19} - 1.1 \times 10^{-19} = \boxed{2.9 \times 10^{-19}\,\text{J}}$.

$\boxed{2}$ (c) **B** We could turn off the flow of electrons by changing the light's

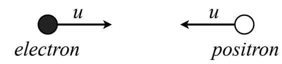
A) brightness **B)** color **C)** polarization

$\boxed{3}$ 13. **A** This graph shows a wavefunction $\psi(x)$. If $P(x)$ is the probability that the object will be found at position x, what is $P(x_A)/P(x_B)$?

A) 0.25 **B)** 0.5 **C)** 2 **D)** 4 **E)** 8



14. An electron and a positron are moving towards each other at $u = 0.6$ (in $c = 1$ units) and $\gamma = 1.25$. The rest mass of an electron to 0.5 MeV. Answer the following questions in $c = 1$ units.



$\boxed{3}$ (a) What is the total energy of the electron, in MeV?

$$E = \gamma m = (1.25)(0.5\,\mathrm{MeV}) = 0.625\,\mathrm{MeV}$$

$\boxed{3}$ (b) What is the total kinetic energy of the electron, in MeV?

$$KE = (\gamma - 1)m = (1.25 - 1)(0.5\,\mathrm{MeV}) = 0.125\,\mathrm{MeV}$$

$\boxed{3}$ (c) What is the momentum of the electron, in MeV?

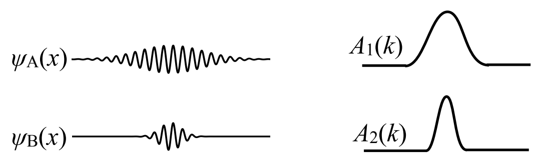
$$p = (\gamma m)u = (0.625\,\mathrm{MeV})(0.6) = 0.375\,\mathrm{MeV}$$

$\boxed{3}$ (d) When the two particles collide, two identical photons are emitted in opposite directions. What is the frequency f of each photon, in Hz? *(Be careful with the units here.)*

$$f = \frac{E}{h} = \frac{0.625 \times 10^{6}\,\mathrm{eV}}{4.14 \times 10^{-15}\,\mathrm{eV \cdot s}} = 1.5 \times 10^{20}\,\mathrm{Hz}$$

$\boxed{2}$ 15. **B** The figures show two wavefunctions, $\psi_A(x)$ and $\psi_B(x)$, and their two Fourier transforms $A_1(k)$ and $A_2(k)$, not necessarily in that order. $A_1(k)$ is the Fourier transform of which of the wavefunctions?

A) $\psi_A(x)$ **B)** $\psi_B(x)$



16. Consider a plane wave, i.e. a solution to the forceless Schrodinger equation

$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} = i\hbar\frac{\partial\Psi}{\partial t}$$

with $k = 0.1\,/\mathrm{m}$ and mass $9 \times 10^{-31}\,\mathrm{kg}$.

$\boxed{3}$ (a) Find the plane wave's angular frequency ω.

$$\hbar\omega = \frac{\hbar^2 k^2}{2m} \implies \omega = \frac{\hbar}{2m}k^2 = \frac{1.055 \times 10^{-34}\,\mathrm{J\cdot s}}{2(9 \times 10^{-31}\,\mathrm{kg}}(0.1)^2 = 5.9{\times}10^{-7}\,\mathrm{rad/s}$$

$\boxed{3}$ (b) Write the plane wave $\Psi(x,t)$ in terms of x and t, and no other variables. Ignore the normalization constant.

$$\Psi(x,t) = e^{i(kx-\omega t)} = e^{i(0.1x-5.9\times10^{-7}t)}$$