1. An unstable particle has a (proper) lifetime of 3.39×10^{-8} seconds. A beam of such particles is produced at an accelerator when protons hit a target. The particles move through the laboratory at speed 0.981 c. How far do the particles travel from the target before they decay? Give your answer in meters to three significant figures. $t_{proper} = 3.39\times10^{-8}s$ $t_{Lab} = \gamma t_{prop}$

$d = v \times t_{Lab} = \frac{0.981 \times 3.00\times10^{8}}{\sqrt{1-.981^2}} \times 3.39\times10^{-8} = 51.4\ m$

2. The ϕ is an unstable particle of mass of $mc^2 = 1020$ MeV. It decays into two π mesons 7.30×10^{-3} percent of the time. For the π mesons, $mc^2 = 140$ MeV. Suppose the ϕ is at rest when it decays. What is the speed of each π meson? Give your answer as a multiple of c, to three significant figures. Each π has

$E = 510\ MeV = m_\pi c^2 \gamma$, so $\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \frac{510}{140}$

$v = .962\ c$

3. The work function of a certain metal is 2.24 electron-volts. The longest wavelength (in nm) for which light is able to produce photoelectrons is:

$\frac{hc}{\lambda} = 2.24eV$, $\lambda = \frac{1240}{2.24}\ nm$

$= 554\ nm$

4. The energies of the hydrogen levels are $-(13.6eV)/n^2$. Singly ionized helium differs from hydrogen by having a nucleus of charge +2e. What is the wavelength of the photon emitted by singly ionized helium when it makes a transition from the n=4 state to the n=3 state? Give your answer in nm, to three significant figures.

$13.6\ Z^2\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \frac{hc}{\lambda} = 2.644ev$ $\lambda = 469\ nm$

16. The wavelength of photon A is twice that of photon B. What is the ratio of the speed of photon A to that of photon B?

All photons travel at c!

a) 1/2
b) 2
c) 1/4
d) 4
→e) 1

17. An astronaut travels from the earth and back to a star 4.8 light years away (as seen by an observer on the earth), at a speed of 0.8 c (relative to the earth). When he returns to the earth, an observer who has stayed at home will have aged:

a) 9.6 years
b) 7.2 years
→c) 12 years
d) 5.8 years
e) 16 years

From Earth, each half takes $\frac{4.8}{.8} = 6\ yr$

so twin on Earth ages $2 \times 6 = 12\ yr$

18. Which of the following statements are true?

- I: A proton confined within a nucleus cannot be perfectly at rest. true, as confined, $\Delta p \neq 0$
- II. A particle of finite lifetime cannot have a precisely defined rest energy. true, as $\Delta E \geq \frac{\hbar}{2\tau}$
- III. The position and momentum of a particle cannot be simultaneously measured to arbitrary accuracy.

true

a) II and III are true; I is false
→b) All three statements are true
c) All three statements are false
d) III is true; I and II are false
e) I and III are true; II is false

19. Two rockets each move with speed 0.4 c in opposite directions in the laboratory frame of reference. What is the speed of one rocket, as determined by an observer in the other?

$\frac{0.4 + 0.4}{1 + (0.4)^2} c = .690\ c$

→a) .69 c
b) .57 c
c) .44 c
d) .75 c
e) .8 c

20. The mass of a particle is m. In order for its **total** energy to be three times its rest mass energy, its momentum must be:

a) $\sqrt{3}mc$
→ b) $\sqrt{8}mc$
c) $\sqrt{2}mc$
d) $\sqrt{5}mc$
e) $\sqrt{6}mc$

$E^2 - p^2c^2 = m^2c^4 = 9m^2c^4 - p^2c^2$
$p = \sqrt{8}\,mc$

21. A single beam of neutral atoms splits into 7 distinct beams when it is sent through an inhomogeneous magnetic field (Stern-Gerlach experiment). We can conclude that the magnitude of the total angular momentum of the neutral atom is:

a) $7\,\hbar$
b) $6\,\hbar$
c) $\sqrt{56}\hbar$
→ d) $\sqrt{12}\hbar$
e) $3\,\hbar$

splitting $\propto m_\ell$, so number of different m_ℓ is 7
There are $2\ell+1$ m_ℓ's, so $\ell = 3$
$|L| = \sqrt{3(3+1)}\,\hbar = \sqrt{12}\,\hbar$

22. Which of the following statements about the photoelectric effect are true?

- I: The stopping potential increases with the frequency of the incident light. true
- II. The stopping potential increases with the intensity of the incident light. No. Only the number of electrons depends on intensity
- III. The photocurrent increases with the intensity of the incident light. true

a) II and III are true; I is false
b) I and II are true; III is false
c) I is true; II and III are false
d) All three statements are true
→ e) I and III are true; II is false

23. The K_α line emitted by an X-ray tube has a wavelength of 0.0228 nm. What is the atomic number Z of the material in the target?

a) 73
b) 56
c) 75
→ d) 74
e) 57

For K_α,
$E = 13.6(Z-1)^2\left(1-\frac{1}{4}\right)$ eV
$= \frac{1240}{.0228}$
$Z-1 = 73$
$Z = 74$

24. An electron has a DeBroglie wavelength of 0.0013 nm. What is its kinetic energy? $mc^2 = 0.511$ MeV

→ a) ABout 0.57 MeV
b) About 0.44 MeV
c) About 0.89 MeV
d) About 0.95 MeV
e) About 1.08 MeV

$p = \frac{h}{\lambda} = 5.097\times10^{-22}$ kg m/s
$pc = 1.528\times10^{-13}$ J
$= 0.9539$ MeV
$E^2 = (pc)^2 + (mc^2)^2 = 1.171$ MeV
$E = 1.082$ MeV $\quad K = E - mc^2 = .571$ MeV

25. A particle has a normalized wave function $\psi(x) = (2x/L^2)^{1/2}$ in the region $0 < x < L$. What is the probability that at any instant the particle lies between $x = 0$ and $x = L/3$?

a) Zero
b) About 33%
c) About 67%
d) About 82%
→ e) About 11%

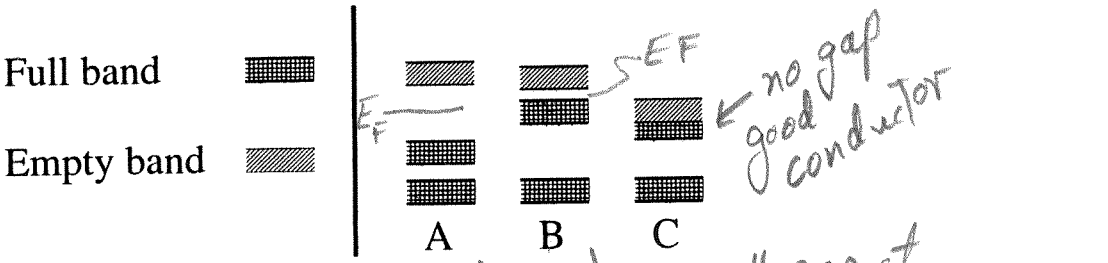
$P(0 \le x \le L/3) = \int_0^{L/3} \psi^2(x)\,dx$
$= \int_0^{L/3} \frac{2x}{L^2}\,dx = \frac{x^2}{L^2}\Big|_0^{L/3} = \frac{1}{9}$

26. Phosphorus has atomic number Z = 15. In the ground state, what is the configuration of its outermost electrons?

a) $3p^1\,4s^2$
b) $2p^{11}$
c) $3p^5$
→ d) $3p^3$
e) $3p^2\,4s$

full K shell has 2 electrons
full L shell has 8 electrons
$n=3$ shell has 5,
2 in 3s
3 in 3p
Outermost are the 3 in the 3p subshell

27. The band structure of three solids are shown



Solids A, B, C are respectively

a) insulator, insulator, metal
b) semiconductor, metal, insulator
→ c) insulator, semiconductor, metal ←
d) insulator, insulator, insulator
e) metal, metal, insulator