Solutions to Exam 2; Phys 100

Photons: $E = hf$.
Kinetic Energy: KE $= \frac{1}{2}mv^2$
Uncertainty principle: $\Delta x \Delta v \geq h/m$.
Atomic number: # protons; Mass number: # protons + # neutrons.

1. (5 points) Given that the strong nuclear force can hold protons together in the nucleus, and the fact that the effects of the strong force are not noticeable beyond nuclear distances, what can we conclude?

(a) Gluons are made out of quarks and antiquarks bound together

(b) Gravity is *not* a negligible force for subatomic particles

(c) The strong force falls off faster than an inverse-square law with distance

(d) Neutrons are heavier versions of neutrinos that are affected by the strong force

(e) The weak nuclear force must also have a part in holding nuclei together

2. (5 points) In the uncertainty principle, what does the quantity Δx refer to?

(a) The difference between successive measured values of a particles' position x

(b) The de Broglie wavelength of a large number of electrons making up an experimental sample

(c) The likelihood of obtaining an exact measurement of x, if given an exact value of v

(d) A statistical measure, akin to standard deviation, describing the probability distribution for x

(e) The experimental error in x measurement introduced by the imperfections of equipment

3. (5 points) You shine pure green light on a metal, and find that you observe electrons being knocked out from the metal. Which of the following statements is consistent with that fact?

(a) Red light also knocks out electrons, while blue does not

(b) Neither infrared nor ultraviolet photons knock out any electrons

(c) Neither blue nor ultraviolet light knocks out any electrons

(d) Both red and blue light also knocks out electrons

(e) Only green light knocks out electrons

4. (5 points) What is the significance of the double slit experiment using electrons?

(a) It demonstrates spectral lines with different colors, due to different atomic energy levels

(b) It produces an interference pattern, showing that electrons can behave like waves

(c) It connects Planck's constant to the speed of light

(d) It shows how electrons have antiparticles

(e) It shows how Helium might be obtained from the fusion of electrons

5. (5 points) Which of the following is true about photons?

(a) A photon's speed depends on its wavelength

(b) It is impossible to measure single photons

(c) Photons are particles, and so are not subject to interference like waves are

(d) Photons always travel backwards in time

(e) A photon's energy is proportional to its frequency

6. (5 points) Which of the following is *not* a feature of quantum mechanics not seen in Newtonian physics?

(a) Fundamentally random events

(b) Discrete (not continuous) energy levels

(c) The uncertainty principle

(d) Negative mass being impossible

(e) Wave-particle duality

7. (5 points) You start with a sample consisting of 1000 radioactive nuclei. All these nuclei are the same, and they have a half-life of 2 days. Among the following, which is the most likely number of undecayed nuclei you will have in the sample, after 8 days?

(a) 168

(b) 125

(c) 101

(d) 59. (Closest to $1000/2/2/2/2 = 62.5$.)

(e) 18

8. (5 points) Among astrophysicists and astrobiologists, which would be considered a respectable view concerning life in the universe?

(a) Life has to be very rare, because only a tiny fraction of stars have planets

(b) Intelligent life is common, and we are certain aliens have visited Earth in the past

(c) Simple, bacterial life forms might be common, but intelligent life forms are rare

(d) Life can only exist on Earth and nowhere else in the universe

(e) Such speculation is science fiction that does not attract the attention of serious scientists

9. (5 points) According to our best current understanding,

(a) Frictional forces are due to gravity

(b) All forces are mediated by an exchange of particles

(c) No forces existed until 1 billion years after the big bang

(d) The strong nuclear force is caused by a dimensional rift

(e) Dark matter is not affected by any known forces

10. (5 points) What is the primary source of all atomic nuclei heavier than Hydrogen and Helium in the universe?

(a) Explosions of stars, known as supernovae

(b) The big bang (origin of the universe)

(c) Gamma radiation

(d) Hydrodynamic wormhole convolutions

(e) Clouds of gas and dust at very low temperatures

11. (5 points) The first few energy levels for an electron in an atom are $E_1 = 0$, $E_2 = 8$, $E_3 = 12$, $E_4 = 13$, in units of 10^{-18} J. Which of these quantum jumps creates the highest frequency photon?

(a) Level 3 to level 1. (Highest energy difference.)

(b) Level 4 to level 2

(c) Level 2 to level 1

(d) Level 3 to level 2

(e) Level 4 to level 3

12. (5 points) Which one among the following particles is composed of quarks?

(a) photons

(b) antineutrinos

(c) protons

(d) electrons

(e) gluons

13. (5 points) You see line spectra in dilute gases under a high voltage because

(a) The electrons of the gas atoms jump between energy levels, emitting photons

(b) The metal plates at the ends of the gas tube eject protons at the photoelectric cutoff frequency

(c) The neutrons in the gas nuclei become protons through β^- decay

(d) Gluonic excitations decohere close to the thermal boundary of the spectroscope

(e) Diffraction gratings only transmit certain frequencies of visible light

14. (5 points) For each of the following nuclear decays, where a nucleus A becomes nucleus B, indicate in the blank space whether the omitted decay product is an α, β^-, or γ or if the decay described is a **mistake** (neither α, β^-, nor γ fits).

(a) ${}^{230}_{90}\text{A} \rightarrow {}^{220}_{80}\text{B} + \underline{\textbf{mistake}}$

(b) ${}^{230}_{90}\text{A} \rightarrow {}^{230}_{91}\text{B} + \bar{\nu}_e + \underline{\beta^-}$

(c) ${}^{230}_{90}\text{A} \rightarrow {}^{226}_{88}\text{B} + \underline{\alpha}$

(d) ${}^{230}_{90}\text{A}^* \rightarrow {}^{230}_{90}\text{A} + \underline{\gamma}$

(e) ${}^{230}_{90}\text{A} \rightarrow {}^{231}_{89}\text{B} + \mu^- + \underline{\textbf{mistake}}$

15. (10 points) What is antimatter? Does it have negative mass? What happens when it combines with ordinary matter?

Answer: Elementary particles have antiparticle counterparts—a particle that has the *same* (non-negative) mass, but the opposite charge. For example, there are quarks and antiquarks, neutrinos and antineutrinos, electrons and positrons. When a particle and its antiparticle comes together, they annihilate, producing energy, typically in the form of high-energy photons such as gamma rays.

16. (10 points) The mass of four Hydrogen atoms is very close to that of one Helium atom. Which is the lower energy state—will you release energy by the fusion reaction $4\text{H} \rightarrow \text{He}$ or by the fission reaction $\text{He} \rightarrow 4\text{H}$? Given your answer, how do you explain why Hydrogen is more abundant in the universe than Helium?

Answer: The fusion reaction will release energy; hence He is the lower energy state. (Note: the inverse fission reaction will therefore *require* energy, it does not release energy.) You shoudl recall that fusing Hydrogen into Helium is how the sun produces its energy. Hydrogen is more abundant because even though it's the lower energy state, it is not easy to make He by fusing 4H. There's an energy barrier that has to be overcome when making the transition from the 4H state to He.

17. (15 points) Listed below are the steps in a calculation estimating the minimum energy (E_{min}) of a one-dimensional particle with mass m confined to a wire of length L, using the uncertainty principle. As in the example, *briefly* explain, in the space provided, how and why each step works. Don't bother saying "square the length" and other obvious things—just describe the physical reasoning going on.

$\Delta x\,\Delta v \approx \frac{h}{m}$	The uncertainty principle gives an estimate of the product of uncertainties in position and speed. We drop the 4π because this is an estimate.
$\Delta x \approx L$	Since the particle is confined to a region of size L, its uncertainty in position can be estimated to be L.
$\Delta v \approx \frac{h}{mL}$	We now put our estimate for Δx into the first equation.
$\Delta v \approx v$ for $v \approx 0$	For speeds close to zero, the expected speed will be close to the uncertainty in speed.
$v \approx \frac{h}{mL}$	Therefore the speed can be estimated as about the speed uncertainty estimate we already made.
$E_{\text{min}} = \frac{1}{2}mv^2$ (only)	The only relevant energy for a particle in a box is its kinetic energy.
$E_{\text{min}} \approx m\left(\frac{h}{mL}\right)^2 = \frac{h^2}{mL^2}$	The minimum energy is the kinetic energy for the minimum speed estimated, so we can put everything together.

18. (15 points) Explain why the planetary model of atoms does not work—why atoms would not be stable under classical physics. Use the fact that accelerating charges radiate electromagnetic radiation. Energy concepts will be important in your reasoning; spell out exactly what sorts of energy and energy transformations are involved in your explanations.

Answer:

- The electron and proton have equal and opposite electric charges.
- Opposite electric charges attract one another.
- This leads to a bound state where the electron orbits the proton.
- If a charge orbits another, it does not travel in a straight line.
- Anything not traveling in a straight line has non-zero acceleration.
- Accelerating charges must radiate electromagnetic waves.
- Electromagnetic waves carry energy.
- Energy is conserved.
- Therefore, the radiated energy must come from the atom.
- If an atom loses energy, the orbiting electron quickly spirals closer to the nucleus.

19. (15 points) A philosophy major thinks that nothing is truly random. She points at a coin flip: it isn't random, it's just complicated. If we had a precise accounting of all the forces involved in the flip, and the precise conditions as the coin travels through the air, we could predict exactly whether heads or tails would come up. She says that maybe quantum randomness is merely an expression of our ignorance of what is really going on. How would you respond to this argument? Why do most physicists think the randomness in quantum physics is unlike that of a coin—that it is fundamental randomness?

Answer: Most physicists think that there is a crucial difference between a coin flip and the randomness in quantum events. And this comes down precisely to the fact that it is possible to gather more information to improve our ability to predict a coin flip, while we cannot do the same with quantum events. With a coin, we know what it is that we don't know, and we know how to get extra information if we are willing to invest the required resources. With a quantum event, we have no idea what we don't know or how to get extra information. If something is unknown in the quantum case, it is indistinguishable from the nonexistent.

20. (15 points) Imagine that someone were to argue that

(a) Classical (19th century) physics is completely mistaken. It has no concept of quantum phenomena, and no clue about the nature of particles and forces.

(b) There is no need to learn classical physics except as part of intellectual history. It is a curiosity with no practical value.

(c) We can be pretty sure that the physics in our textbooks today will also be superceded in time. Future generations will consider today's physics to be mistaken.

(d) There is no point in learning today's physics, because it is also very likely to be false.

Discuss and give reasons why you agree or disagree with (a), (b), (c) and (d).

Answer:

(a) Classical physics is *not* completely mistaken. It does a lot of things very well, and is an excellent approximation to explain most things we will ever encounter. Yes, it is inadequate for certain things, which is the reason we need quantum physics, but that does not mean it is mistaken across the board.

(b) Intellectual history is valuable in its own right. Nevertheless, there is immense practical value in classical physics. It is the basis for mechanical and civil engineering, and much of electrical engineering. Imagine modern technology without such engineering knowledge.

(c) Yes, it is quite likely (though we should not make guarantees) that present physics will be superceded. But this does not mean it will be seen as *mistaken*. More likely, it will appear limited, as something that needed to be extended as we learned more about the universe.

(d) Physics today is not the complete story. We know this. But it is not *false* in a blanket sense. The history of physics is one of increasingly sophisticated and powerful approximations. None of it is false in the same sense that "the sky is green" is false.