Solutions to Exam 2; Phys 100

Kinetic energy: $\frac{1}{2}mv^2$.
Uncertainty principle: $\Delta x \Delta p \geq h/4\pi$.

1. (5 points) In the experiment you did with an electron beam hitting a screen and being deflected by electric and magnetic fields, what is a reasonable estimate for the location uncertainty Δx of one of the electrons within the beam?

(a) 2×10^{-5} m

(b) 2×10^{-3} m

(c) 2×10^{-1} **m**

(d) 2×10^{1} m

(e) 2×10^{3} m

2. (5 points) The "planetary model" of the hydrogen atom as a proton with an electron moving in orbit around it is extremely oversimplified. The main thing wrong with it is

(a) the electron is actually much larger than the proton

(b) the electron should not be pictured as having both a specific position and a specific velocity

(c) actually there are several electrons going around in the hydrogen atom

(d) the weak nuclear force is not strong enough to hold the hydrogen atom together

(e) the effects of alpha decay need to be accounted for

3. (5 points) Which of the following is *correct* about quantum physics?

(a) We cannot use quantum physics to communicate at speeds faster than light

(b) Quantum physics means that time is equivalent to space

(c) The fact that atomic nuclei exist violates quantum physics

(d) Quantum physics is irrelevant to the operation of electronic devices

(e) Quantum physics does not apply to very small objects

4. (5 points) Which of the following is likely to be composed of particles not accounted for in the standard model of particle physics?

(a) Living things

(b) The cores of old stars

(c) Radio waves

(d) Dark matter

(e) Atomic nuclei

5. (5 points) We know that the strong nuclear force between protons and neutrons is stronger than electromagnetism for distances smaller than about 10^{-15} m. and weaker than electromagnetism for larger distances. What, therefore, can we conclude?

(a) The strong force must be mediated by electrons

(b) Photons do not interact with protons at distances smaller than 10^{-15} m

(c) Dark energy agglomerates neutrinos with tachyons

(d) In the nucleus, the momentum uncertainty $\Delta p > 10^{-15}$ m

(e) The strong force must not vary as the inverse square of distance

6. (5 points) We can be virtually certain that if we have a 1.000 kg sample of radioactive material, after exactly one half-life passes exactly 0.500 kg of the same radioactive material will remain. Why?

(a) It's a law of quantum physics that exactly half the radioactive nuclei in a given sample will decay after a half-life

(b) The uncertainty principle means that you will lose information about the location of half the nuclei during a half-life

(c) Microscopic black holes cause tidal forces that destabilize atomic nuclei

(d) With a very large population of nuclei, the relative size of quantum statistical fluctuations is very small, so averages become very exact

(e) Your choice of observing a particular sample of nuclei will determine the half-life and the exact outcome of the measurement of its mass

7. (5 points) Which of the following is true?

(a) All of the iron in the universe was manufactured immediately after the big bang

(b) The sun is a massive thermonuclear explosion fueled by the fission of very heavy nuclei such as uranium

(c) Any element heavier than Lithium in our bodies was manufactured in stars or the violent death of stars

(d) Most of the "heavy water" in our oceans is produced by Hawking radiation from evaporating black holes

(e) The precise origin of nuclei lighter than iron can be identified by performing quantum hyperbolometry

8. (5 points) Why hasn't all the atomic Hydrogen in the universe fused together to create Helium?

(a) The mass of Helium is larger than the mass of four Hydrogen atoms

(b) There is not enough uranium in the universe to catalyze the fission reactions

(c) The uncertainty principle prohibits Hydrogen atoms from coming close to each other

(d) $E = mc^2$ means that coriolar nuclear forces dampen the production ratio

(e) Fusion can only take place in extreme environments such as the cores of stars

9. (5 points) Quantum mechanics does not support the notion of "libertarian free will" because

(a) The uncertainty principle applies only to particles such as electrons, while brain processes are driven by photonic interactions

(b) The Voinovitch limitation effect means that quantum fluctuations obscure all human decision making processes

(c) Free will is not the same thing as a random choice, and quantum mechanics only adds randomness to the relevant physics

(d) Philosophers have already solved questions about free will using only classical, non-quantum physics

(e) Our decisions depend on gravity, but we do not yet have a good theory of quantum gravity

10. (5 points) Which is *false* about the kind of black holes encountered in astronomy?

(a) Tidal forces close to a black hole can rip objects apart

(b) It is impossible to be in a stable orbit around a black hole

(c) Time slows down close to a black hole

(d) A black hole has a temperature, and radiates energy very dimly

(e) Black holes are characterized by escape velocities greater than the speed of light

11. (5 points) According to the standard model, which if the following is *not* an elementary particle?

(a) antineutron

(b) neutrino

(c) antiquark

(d) photon

(e) electron

12. (5 points) An exoplanet is

(a) A planet orbiting a star other than the Sun

(b) A planet supporting extraterrestrial life forms

(c) An exotic planet in the solar system, such as Saturn

(d) A planet dominated by exothermic reactions

(e) An exoteric planet with anomalous gravity

13. (5 points) The uncertainty principle is due to the physics of

(a) explosions

(b) quarks

(c) muons

(d) symmetry

(e) waves

14. (5 points) The quantum vacuum

(a) has a negative mass

(b) exists only in the vicinity of black holes

(c) is full of short-lived particle-antiparticle pairs

(d) is incompatible with $E = mc^2$ from relativity

(e) is red, green, or blue

15. (5 points) Except for such nuclear processes as nuclear reactors, nuclear bombs, and radioactivity, all of the common forces we see around us daily are due to just two underlying or "fundamental" forces. One of these two forces is gravity. The other is

(a) the frictional force

(b) contact forces

(c) the strong nuclear force

(d) the chemical force

(e) the electromagnetic force

16. (5 points) You start with a sample consisting of 500 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

(e) 30

17. (5 points) Which of the following is among the great unsolved problems in current physics?

(a) Accounting for line spectra of atoms

(b) Detecting light from beyond our galaxy

(c) Achieving a quantum theory of gravity

(d) Demonstrating interference with microwaves

(e) Capturing antineoplastonic quarks

18. (15 points) The planetary model of atoms fails. Accelerating charges radiate electromagnetic waves and lose energy, and therefore orbiting electrons would very quickly spiral in toward the nucleus. But almost exactly the same arguments apply to planets revolving around the Sun. Accelerating masses radiate gravitational waves and lose energy, and therefore orbiting planets should spiral in toward the sun. And yet, the planets have been going around the sun for billions of years.

Consider the following proposed explanations and pick which one seems best. *Explain* why it seems right and the others wrong.

(a) Gravity is a very weak force compared to electromagnetism—we calculated that gravity between particles such as electrons and protons is about 10^{-40} times the strength of their electric interaction. This means that gravitational waves are extremely weak and carry very little energy away. The time scale for the decay of orbits will therefore be just as vastly different in the two cases. Atoms would collapse in a fraction of a second, but planets will revolve around stars for a lot longer than billions of years.

This is correct. It is based on physics you know and have worked with, and it should sound plausible.

(b) Just as quantum mechanics makes stable atoms possible, quantum gravity explains why planetary orbits are stable. The quantum gravitational vacuum includes the random creation and annihilation of black hole and white hole pairs. The white holes have negative mass, creating an antigravitational effect. Vacuum polarization aligns the white holes with planetary orbits, giving them a slight antigravity push that compensates for the energy lost to gravitational waves.

This is nonsense. You will have encountered some of the terms in this paragraph before, but they are used together in weird ways. And you should be suspicious about claims of negative mass and the assumed knowledge of quantum gravity.

(c) Physicists have postulated the existence of a weak cosmic force, alongside gravity as the strong cosmic force. This is similar to the existence of a weak nuclear force along with the strong nuclear force. The weak cosmic force produces a stream of $W^{\pm}$ and Z particles, which make up the solar wind. The wind pushes the planets away just enough to cancel out the weakening of gravity due to gravitational waves.

Nonsense again. If there was anything as important as a "weak cosmic force," you would have heard of it. $W^{\pm}$ and Z particles are associated with the weak nuclear force and are very short-lived.

In the following questions, R is the radius of a spherical mass M, and r is the distance from the center of this spherical mass to a small object with mass m. In all cases, r is larger than R. v is the speed of the small object, and c the speed of light. G is the universal gravitational constant, with units $\mathrm{m}^3/(\mathrm{kg}\cdot\mathrm{s}^2)$, or, equivalently, $\mathrm{J}\cdot\mathrm{m}/\mathrm{kg}^2$.

19. (5 points) You know that the gravitational potential energy must *increase* as r becomes larger. Which of the following is therefore a possible expression for this potential energy?

(a) GmR

(b) Gc^2/r^2

(c) $-GM^2r$

(d) GcR

(e) $-GmM/r$ **Right units, correct behavior with increasing** r**.**

20. (5 points) If the small object is launched with the escape velocity v_e, it will have total energy $\frac{1}{2}mv_e^2$ (the kinetic energy) plus your answer to the previous question with the value $r = R$. When r is very very large, the object must slow down so much that its speed $v = 0$. What, then, is the total energy when r is very very large?

(a) $-GmR$

(b) $-Gc^2/r^2$

(c) 0 **The potential and kinetic energies both approach zero**

(d) Gm^2/v_e

(e) ∞

21. (5 points) Since energy is conserved, equating the total energy at the point of launch ($r = R$) with the total energy for very very large r. This produces an equation physicists can solve for the escape velocity v_e. What is this equation?

(a) $\frac{1}{2}m^2v_e + GmR = -GmR$

(b) $\frac{1}{2}mv_e^2 + Gc^2/r^2 = Gc^2/r^2$

(c) $\frac{1}{2}mv_e^2 - GmM/R = 0$ **This directly follows from the previous question**

(d) $\frac{1}{2}mv_e - G^2 = Gm^2/v_e$

(e) $\frac{1}{2}mv_e^2 = \infty$

22. (5 points) When physicists solve this equation and then set $v_e = c$, they obtain the radius of the event horizon of a black hole. This is

(a) $2GM/c^2$ **Solves equation, correct units**

(b) $Mm/2$

(c) $-Gm^2c^2$

(d) $R^2/2m$

(e) Gmr^2

If you're uncomfortable with the math, ask me to look over what you've done. If it looks to me like you're lost and don't know what you're doing, I'll tell you to leave it and write down a paragraph below about what you know about black holes, for partial credit. *Don't do this without consulting me!*

23. (15 points) Say you read a book on "quantum healing." You encounter claims that quantum mechanics implies that we create our own reality through our free choices, that every particle in the universe is connected through invisible, faster-than-light quantum influences, and that therefore we can will ourselves back to health and even choose to prevent aging. You then recall our class discussions about how quantum probabilities depend on our choice of particular measurements to make. Given this,

(a) Do the "quantum healing" claims sound plausible or implausible to you? Your answer will depend on whether you trust the community of physicists—give some reasons why you trust or distrust physicists. (I'm not looking for a pre-set answer here.)

Answer: I'm hoping it will sound implausible to you, as it is essentially nonsense. There are some superficial parallels to choices of what to measure in the "creating your own reality" scenario, but no awareness of the randomness of results, which prevents any notion of choosing particular outcomes.

I also hope you have good reason to trust physicists, but if you can articulate your reasons for distrust, such an answer would also be acceptable.

(b) What would you do if you wanted to learn more and find out whether such claims are correct or not—what kind of information would you need to convince you one way or the other?

Answer: What you should be looking for in the way of new information to convince you is largely *evidence*. You can check with physicists to see if there is any real basis in physics for "quantum healing" (there isn't). You can check with medical doctors to see if there is any substantial research (large numbers of subjects, double-blind studies) that supports "quantum healing" outcomes. Quantum healing involves some very revolutionary claims, so just a few ambiguous case studies or personal experiences are not worth much as evidence.

24. (15 points)

(a) Give an example of a question you would consult a physicist in order to get an answer. This should be a question we have *not* discussed in class. "Why is the sky blue?" would work, as we have not talked about this. But "why do stable atoms exist?" would not, since we have discussed this. Explain why you think your question belongs in the realm of physics rather than elsewhere.

Answer: For example: Why do some objects conduct electricity well, while others do not?

This is a physics question because it concerns fundamental physical properties of materials. A physicist would know something about the structure of materials and how electrons move within them.

(b) Give an example of a question you would *not* consult a physicist about. Then explain why, even if physicists have a good idea how the world works at a fundamental level, they would not have much useful to say about your particular question.

Answer: For example: Should interest rates be adjusted up or down to keep the current level of economic growth?

Though economic systems are made up of physical particles and interactions, they are so far removed from the basic physical level of operation that a physicist cannot use her knowledge about forces or electrons in any meaningful way to answer such a question.