

1. (5 points) According to Heisenberg's uncertainty principle,  $\Delta x \Delta p \geq h/4\pi$ , decreasing uncertainty about the location of a particle comes at the expense of increasing uncertainty about its

- (a) Pressure
- (b) Probability
- (c) Mass
- (d) Momentum**
- (e) Intersubjectivity

2. (5 points) Which of the following is *not* a major difficulty for practical (fast) interstellar space travel with human crews?

- (a) The need for high accelerations that humans can't survive
- (b) Huge amounts of fuel needed to achieve speeds close to light
- (c) The lack of shortcuts such as navigable wormholes
- (d) Planet-antipplanet pairs that exist in the quantum vacuum**
- (e) The impossibility of warp drive without probably nonexistent negative mass

3. (5 points) A wormhole

- (a) Consists of an inverted black hole that spews matter out all the time
- (b) Is a pure science fiction invention with no basis in physics
- (c) Would, if real and stable, act as a shortcut between far-apart regions of spacetime**
- (d) Exists at the center of every gas giant
- (e) Illustrates the Einstein-Griffiths paradox in quantum gravity

4. (5 points) If you put water under high enough pressure you can achieve

- (a) Nuclear fission
- (b) Accelerated beta decay
- (c) Ice, even at high temperatures**
- (d) Extremely low gravity
- (e) Large increases in length dilation

5. (5 points) You have a radioactive sample in the lab with a half-life of 60 days. You measure its activity in a lab where the background radiation is 2 counts/second, and find 8 counts/second. What would you have measured the activity to be 180 days ago, when the sample was just bought?

- (a) **50 counts/second**
- (b) 61 counts/second
- (c) 69 counts/second
- (d) 70 counts/second
- (e) 94 counts/second

6. (5 points) Which of the following is *not* one of the fundamental forces of nature?

- (a) **Friction**
- (b) Electromagnetism
- (c) Gravity
- (d) The weak nuclear force
- (e) The strong nuclear force

7. (5 points) Which of the following photons has the highest energy?

- (a) Infrared, because infrared indicates heat
- (b) Red, because that is the warmest visible color
- (c) Green, because it's the color for photosynthesis
- (d) Violet, because it is the coolest visible color
- (e) **Ultraviolet, because it has the highest frequency**

8. (5 points) What does "space opera" refer to?

- (a) An avant-garde musical performance on a space station
- (b) **A genre of science fiction where events take place at galactic scale**
- (c) High-frequency sound wave patterns within gas giant atmospheres
- (d) A short musical act taking place during a scene change in a grand opera
- (e) Congressional debates over funding of the US space program

9. (5 points) Which of the following is a theory of gravity?

- (a) Quantum mechanics
- (b) General relativity**
- (c) Time dilation
- (d) The center of a gas giant
- (e) Stellar evolution

10. (5 points) Imagine that you were in a spaceship going at 99.9% of the speed of light relative to Earth. Which of the following would be true?

- (a) Everything in the spaceship would move as in slow motion
- (b) You would see every object in the spaceship as smaller than usual
- (c) Everything inside the spaceship would look and act as normal**
- (d) You would see every object in the spaceship as larger than usual
- (e) Everything in the spaceship would move as if it were speeded up

11. (5 points) Which of the following is *not* an “existential risk”—a risk that threatens human civilization—that scientists today worry about?

- (a) Superintelligent AI’s that get out of human control
- (b) Global warming
- (c) Nuclear warfare
- (d) Earth colliding with a black hole**
- (e) Cheap genetic engineering creating a superlethal virus

12. (5 points) The pressure you experience within a fluid is due to

- (a) Quantum measurement
- (b) The magnetic field of the Earth
- (c) The small difference between the masses of quarks
- (d) The weight of the fluid column above you**
- (e) The speed of light being constant in all reference frames

**13. (5 points)** Quantum mechanics is not directly relevant to one of the following questions. Which one?

- (a) The behavior of the very early universe, just after the big bang
- (b) How to pack more and more computer memory into smaller circuits
- (c) The structure of the periodic table of elements
- (d) The psychological component of medical treatments**
- (e) How to understand the interaction of materials with gamma radiation

**14. (5 points)** In what kind of path would the planets move if no force acted on them?

- (a) They would continue in their present orbits, since they already have no force on them
- (b) Larger elliptical orbits
- (c) Parabolas, like any projectile
- (d) Straight line with an acceleration of  $9.8 \text{ m/s}^2$
- (e) Straight line with constant speed**

**15. (5 points)** Will the Earth ever collapse to form a black hole?

- (a) No; it's not massive enough**
- (b) Yes, once the radioactivity of its core is exhausted
- (c) No; it doesn't have enough Hydrogen
- (d) Yes; all rocky planets become black holes
- (e) No; it's too far away from the galactic core

**16. (5 points)** Which of these features in *The Algebraist* is unlikely according to our current understanding of physics?

- (a) Machine sentience
- (b) Treatments that can extend human life for centuries
- (c) Craft capable of travel into the depths of gas giants
- (d) The existence of a religion such as "The Truth"
- (e) A galaxy-spanning network of stable wormholes**

**17. (5 points)** Suppose you observe a single radioactive nucleus. The length of time until that particular nucleus decays is

- (a) unpredictable because of the practical difficulties of obtaining all the information needed to make the prediction
- (b) unpredictable because of fundamental uncertainties arising from quantum physics**
- (c) predictable only if the speed of light does not fluctuate
- (d) predictable, provided you know the precise nuclear state of this nucleus
- (e) predictable from the known half-life of the nucleus

**18. (5 points)** Which of the following is an argument used to suggest that intelligent, technology-using alien life is not very common in the universe?

- (a) Quantum mechanics makes life of any form extremely improbable
- (b) The Fermi paradox: if they exist, they should have already been here**
- (c) Gas giants are extremely rare, and therefore life does not have many opportunities to evolve
- (d) The universe contains too many black holes that suppress gamma radiation
- (e) The Heisenberg uncertainty principle makes alien life forms almost impossible to detect

**19. (5 points)** According to Newtonian physics, force is proportional to

- (a) Diameter
- (b) Velocity
- (c) Acceleration**
- (d) The speed of light squared
- (e) Planck's constant

**20. (5 points)** Which of the following is *false*?

- (a) Objects, whether they are moving or not, do not contain forces
- (b) The velocity of an object can be zero even if the position is changing**
- (c) Any change in velocity must be due to a net force
- (d) All interactions involve change, and therefore forces
- (e) The acceleration of an object can be non-zero even at an instant when its velocity is zero

**21. (20 points)** Fill in approximate (ballpark) values for the following, using the following numbers:  $10^{-15}$ ,  $10^{-10}$ , 1,  $10^2$ ,  $10^5$ ,  $10^7$ ,  $10^{10}$ ,  $10^{17}$ ,  $10^{24}$ .

- (a) Radius of the Earth:  $10^7$  m
- (b) The distance to the star nearest to the Sun: 1  $c$ -years
- (c) The mass of a typical adult human:  $10^2$  kg
- (d) Size of our galaxy (the Milky Way):  $10^5$   $c$ -years
- (e) Size of an atom:  $10^{-10}$  m
- (f) Number of electrons in the most common element in the universe: 1
- (g) Size of an atomic nucleus:  $10^{-15}$  m
- (h) Number of atoms in an everyday object:  $10^{24}$
- (i) Age of our universe:  $10^{10}$  years
- (j) Number of Joules of energy in a mass of 1 kg ( $c = 3 \times 10^8$  m/s):  $10^{17}$

**22. (20 points)** The charge of an electron is  $-1.60 \times 10^{-19}$  C (C stands for “Coulomb,” the standard international charge unit). The electron mass is  $9.11 \times 10^{-31}$  kg.

The charge of a proton is equal and opposite to the charge of an electron. The mass of a proton is  $1.67 \times 10^{-27}$  kg.

The equation for the electrical attraction between two particles with charges  $q_1$  and  $q_2$  separated by a distance  $d$  is

$$F_E = -k \frac{q_1 q_2}{d^2}$$

Here, the constant  $k = 8.99 \times 10^9$  N·m<sup>2</sup>/C<sup>2</sup>.

The equation for the gravitational attraction between two particles with masses  $m_1$  and  $m_2$  separated by a distance  $d$  is

$$F_G = G \frac{m_1 m_2}{d^2}$$

Here, the constant  $G = 6.67 \times 10^{-11}$  N·m<sup>2</sup>/kg<sup>2</sup>.

- (a) Calculate the ratio of the gravitational attraction between an electron and a proton to the electrical attraction between an electron and proton. (Find  $F_G/F_E$ .)

**Answer:**

$$\frac{F_G}{F_E} = -\frac{G m_e m_p}{k q_e q_p} = 4.41 \times 10^{-40}$$

- (b) In the light of this calculation, explain why physicists working with atomic or subatomic scale phenomena routinely ignore the effects of gravity.

**Answer:**  $4.41 \times 10^{-40}$  is *extremely* small. This means that gravity is utterly negligible compared to electromagnetic forces. Even within nuclei, where  $d$  is small, the strong and weak nuclear forces will completely overwhelm gravity.

- 23. (20 points)** Modern physics is counterintuitive: it often goes against our everyday expectations of how the world should work. Give *two* examples of cases where what you've learned this semester was counterintuitive, and explain how in a paragraph for each case.

**Answer:** Answers will differ; I will grade according to how good an argument you have.

- 24. (20 points)** What do you think might be the *intellectual* value of science fiction? (I'm not interested in whether you find it entertaining.) Illustrate your argument with at least one example involving *The Algebraist*.

**Answer:** Answers will differ; I will grade according to how good an argument you have.

- 25. (20 points)** You took this course because it was a requirement. Given your experience, argue whether students in your position should or should not be required to take a physics course. Use at least one thing you have learned this semester as an example in your argument.

**Answer:** Answers will differ; I will grade according to how good an argument you have.