Solutions to Exam 1; Phys 100

1. (6 points) How would an *Aristotelian* explain the fact that a rock sinks in water?

(a) The atoms that make up a rock have a downward tendency when surrounded by water

(b) Invisible spirits inhabiting rocks cause them to move

(c) Rocks have more internal heat than water, so they tend to sink

(d) Gravity has a stronger effect on rocks than liquid substances

(e) A rock largely consists of the element "earth," whose natural place is lower than water

2. (6 points) In *Newtonian* physics, if we know a planet orbits around the sun without ever changing its speed, what can we thereby conclude?

(a) The velocity of the planet must be constant

(b) The planet must inhabit the heavenly realms that are not subject to decay

(c) There must be a nonzero net force acting on the planet

(d) The acceleration due to gravity is the same throughout the universe

(e) The sun must be pushing the planet along its path

3. (6 points) You throw a ball upward. Ignoring air resistance, which of the following is true on the ball's way up?

(a) Its kinetic energy and nuclear energy both increase

(b) Its nuclear energy converts into thermal energy

(c) Its kinetic energy remains constant while its thermal energy increases

(d) Its gravitational energy increases while its kinetic energy decreases

(e) Its nuclear energy remains constant but its gravitational energy decreases

4. (6 points) Which of the following is *not* true about ancient Greek and medieval physics?

(a) It allows us to make precise calculations of motion

(b) It is close to intuitive, common-sense ideas of physics

(c) It distinguishes between horizontal and vertical movement

(d) It is connected to the Ptolemaic conception of the spheres of the universe

(e) It remained the dominant view until just a few centuries ago

5. (6 points) "Energy" is

(a) a physical substance that objects can absorb or lose

(b) an abstract concept: the ability to do work

(c) the amount of force stored in an object

(d) what you get when you divide force by distance

(e) another name for temperature

6. (6 points) Magnetic forces are produced by

(a) electric charges in motion

(b) stationary magnetic singularities

(c) nuclear reactions in heavy nuclei

(d) relativistic thermoneutral excitations

(e) length contraction but not time dilation

7. (6 points) What distinguishes signals carried by waves and particles?

(a) Waves cannot transmit energy, particles can

(b) Waves cannot travel through outer space, particles can

(c) Waves are affected by length contraction and time dilation, particles are not

(d) Waves can produce interference effects, particles do not

(e) Waves cannot interact with particles, particles can

8. (6 points) Which of the following is a form of electromagnetic radiation?

(a) Sound

(b) Waves on the surface of a lake

(c) Neutrinos

(d) Light

(e) Antimatter

9. (6 points) Which of the following is *not* true about quantum physics?

(a) Particles have wave qualities such as wavelengths associated with them

(b) A photon's energy depends on its frequency

(c) Quantum phenomena strongly violate our commonsense intuitions about the world

(d) Individual quantum events are random

(e) Quantum effects are only noticeable at distances larger than the size of galaxies

10. (6 points) You know that electric forces increase as the charges involved (say q_1 and q_2 for two objects) increase. It should not matter which charge we label "1" and which "2." You also know that the force should decrease as the distance d between the charges increases. Which of the following, then, is a possible expression for the electric force F_E? (k is just an appropriate physical constant.)

(a) $F_E = k\, q_1 q_2 / d^2$

(b) $F_E = k\, q_1 \sqrt{q_2} / d^5$

(c) $F_E = k(q_1 + q_2 + d)$

(d) $F_E = k\, d(\sqrt{q_1} + q_2)$

(e) $F_E = k(q_1 - q_2 / d^5)$

11. (6 points) Jupiter is about 300 times more massive than the Earth. But objects on Jupiter's surface weigh only about 3 times as much. Why?

(a) Magnetic forces on Jupiter counteract gravity

(b) Electric forces on Jupiter counteract gravity

(c) The radius of Jupiter is much larger than Earth

(d) Jupiter is a gas giant; objects float on the gas

(e) Earth is much younger than Jupiter

12. (6 points) Since matter is made of electrically charged particles, why don't we and the objects around us feel electric forces all the time?

(a) Constituents of objects have opposite charges, adding up to electric neutrality overall

(b) The charges need to be activated before we see any effect; normal matter is inert

(c) The electric forces are cancelled out by the magnetic forces.

(d) We *do* feel these forces: that is where gravity comes from

(e) Since these forces act in all directions, they push as often as pull, cancelling out

13. (6 points) We do not notice the effects of special relativity in everyday life because

(a) The electromagnetic forces we encounter are very small

(b) Everyday speeds are much less than the speed of light

(c) Relativity is only applicable in outer space, not on Earth

(d) The Earth's rotation cancels out relativistic effects on motion

(e) The ether surrounds us uniformly, so there is no contrast to notice

14. (6 points) According to general relativity, gravity is due to

(a) Ultraviolet radiation

(b) Energy bending space and time

(c) High frequency thermic oscillations

(d) The difference between particles and waves

(e) The line spectra of dilute gases

15. (6 points) Which of the following is true about the cosmic microwave background radiation?

(a) It corresponds to an extremely cold temperature

(b) It comes from the point in the sky where the big bang took place

(c) It is evidence for the existence of dark matter

(d) It is due to colliding galaxies

(e) It is caused by electromagnetic waves escaping from black holes

16. (10 points) Give examples of situations where the following obtains. Draw a diagram for each. If no such situation is possible, explain why.

(a) The net force on an object is in the same direction as its motion

Answer: If you push a box in a straight line and have its speed increase, the net force and the motion will be in the same direction. Or other similar examples.

(b) The direction of the net force is opposite to the direction of motion

Answer: Toss a ball straight up. While it's on its way up and slowing down, the motion and force will be opposite.

(c) The direction of the net force is perpendicular to the direction of motion

Answer: Have an object revolve in a circular orbit with constant speed. The force will be toward the center of the circle, perpendicular to the motion.

(d) The direction of the net force is perpendicular to the direction of the acceleration

Answer: Impossible, due to $F = ma$. Force is proportional to the acceleration, and mass is never negative, and so force and acceleration are always in the same direction

17. (20 points) You have a cannon that shoots tennis balls at a constant frequency of one ball every second. As the balls fly above you, you can measure the distance between successive balls. Call this the "ball-length."

(a) You now put the cannon on the back of a pickup truck, and have a friend slowly drive it away from you. As the balls continue to fly above you (for a while), will the ball-length you measure increase, decrease, or stay the same? Explain why.

Answer: It will increase. During the time in flight of a ball, the truck will have moved further away before launching the succeeding ball. This will increase the distance between successive balls.

(b) The line spectra astronomers see when observing light from distant galaxies is usually redshifted—the line patterns are the same, but the wavelengths are larger than observed in labs on Earth. Do physicists therefore conclude that redshifted galaxies are moving toward us, away from us, or are stationary relative to us? Explain how your answer to part (a) allows you to answer (b).

Answer: The balls are analogous to wave crests coming toward us. If the source of the waves and detector of the waves (the far away galaxy and us) are moving further apart, the wavelength detected will increase. This is, again, because in the time between successive wave crest emissions, the source and detector will have moved further apart, increasing the wavelength.

18. (50 points) Collisions between cosmic rays and the molecules of our atmosphere often result in the creation of short-lived subatomic particles called muons. When at rest ($s = 0$) in the lab, a muon lives for 2×10^{-6} s before decaying into something else. Let's say a muon is created at an altitude of 5000 m above the earth's surface. At this point, the muon is traveling downward with a speed of $0.995\,c$ (99.5% of the speed of light). A detector at the surface finds that the muon has made it all the way down, and that its speed has not diminished.

(a) If we were living in a Newtonian universe, where Einsteinian relativity did not apply, how far would a muon created at 5000 m altitude travel during its lifetime? Could it make it to the surface?

Answer: Traveling at almost c, the muon would go for $3 \times 10^8 \times 2 \times 10^{-6} = 600$ m. Not far enough.

(b) Calculate the relativistic time dilation factor γ for the muons. (Your answer should be one of the following: 0.1, 0.5, 1, 2, or 10.)

Answer: Use the equation given on the first page:

$$\gamma = \frac{1}{\sqrt{1 - 0.995^2}} = \frac{1}{\sqrt{0.01}} = 10$$

(c) According to relativistic time dilation, $t = \gamma t_0$. In this problem, we have the lifetime of the muons as measured in the muons' own frame of reference and their lifetime as measured from the ground observers' frame of reference. Which one is t, which one is t_0? Is it t or t_0 that is 2×10^{-6} s?

Answer: Since the events of the creation and decay of the muon takes place right where the muon is in its own rest frame, its lifetime in its own frame must be $t_0 = 2 \times 10^{-6}$ s. The ground observer measures t.

(d) According to relativistic length contraction, $L = L_0/\gamma$. In this problem, we have the distance the muon can travel before decaying as measured in the muons' own frame of reference, and the distance it can travel in the ground observers' frame of reference. Which one is L, which one is L_0? Is it L or L_0 that is 5000 m?

Answer: The point of creation and the point of decay are not moving with respect to the ground observer. Therefore the ground observer measures $L_0 = 5000$ m and the muon sees a contracted L.

(e) In the reference frame of the muon, what is the distance between the point it was created and the surface of the earth? What is its lifetime? How long will the muon take to reach the surface? Is it able to reach the surface before it decays?

Answer: Length contraction applies, with $L_0 = 5000$ m. So the muon will see $L = 5000/\gamma = 5000/10 = 500$ m to the surface. Its lifetime stays the same; that's in its own frame of reference already. Traveling nearly at c, the muon will take $500/3 \times 10^8 = 1.7 \times 10^{-6}$ s to get to the surface. This is less than its lifetime, so it will make it.

(f) Now look at the same thing in the reference frame of a surface observer. What is the distance between the point the muon was created and the surface? What is the lifetime of the muon? How long will the muon take to reach the surface? Is it able to reach the surface before it decays?

Answer: Now the distance is 5000 m, since that's in the reference frame of the surface observer. But time dilation applies. So the muon's lifetime will be observed to be $t = \gamma \times 2 \times 10^{-6} = 2 \times 10^{-5}$ s. Traveling nearly at c, the muon would take $5000/3 \times 10^8 = 1.7 \times 10^{-5}$ s to get to the surface. This is less that its extended lifetime as observed from the surface frame of reference, so it will make it.

(g) Are your answers in part (e) and (f) *identical*? Should they be? Are your answers *consistent*? Should they be? (Can whether the muon makes it to the surface depend on the observer's frame of reference?)

Answer: The answers are not all identical, and they should not be—these are different frames of reference, so time intervals and lengths will differ. But they are consistent. After all, the muon either makes it down or it does not; the frame of reference will not change whether or not such an event takes place. The muon makes it down in both sets of calculations, which is as it should be.

(h) Say you have friend who is not aware of relativity and explains this result in Aristotelian terms. She says that the heavens are the realm of perfection, while Earthly objects are susceptible to decay. Since the muon starts out closer to the heavens than a muon on the surface, it naturally lives longer. Her explanation is consistent with the observed results. How would you convince her that the explanation given by relativity is better—what makes Einstein's physics superior to Aristotle's? (There's no hard and fast answer I require here; I just want some intelligent reflection on the question.)

Answer: Relativity gives much more precise, numerical predictions and descriptions of what goes on with the muon. That is a lot more impressive than the vague, qualitative explanation offered by an Aristotelian view, and so it inspires more confidence. Moreover, relativity correctly applies to a vast range of circumstances, while Aristotelian explanations are much more limited in scope and very often dead wrong when you test them.

19. (20 points) Say you encountered the claim that if we were to bore a mine shaft down to the center of the Earth and went down, we would find that our weight would *decrease* as we descended. Indeed, our weight would become zero at the center. Choose one of the three following affirmations or denials, and explain *why* it is more convincing to you than the other options. (Give me your reasoning—not wild guesses or "this one just feels right.")

(a) No, this is not right. The equation for gravitational force (weight) is $F_G = G\, m_1 m_2 / d^2$. Here, d refers to the distance between the *centers* of the masses. So as you approach the center of the Earth, d gets smaller and since you're dividing by d, your weight F_G should increase.

(b) Yes, this is right. As you descend, part of the Earth is now above you. This part will no longer attract you toward the center of the Earth, because that is the opposite direction. In effect, as you descend, the mass of the earth underneath you, m_1, gets smaller as well. When you reach the center, all of the Earth is surrounding you, each bit pulling in its own direction, which all cancels out and you end up with zero.

(c) No, this is not right. The proper description of gravity in very high gravitational fields must involve the bending of spacetime due to very high magnetic fields. $F_G = G\, m_1 m_2 / d^2$ is just an approximation, which is only good close to the surface of the Earth. As we descend into the Earth, the Earth's magnetic pull strengthens, so spacetime is bent more strongly, and hence according to Einstein, our weight should increase as we descend.

Answer: Option (b) is correct. (a) may sound reasonable, but it tries to apply an equation for point masses to the interiors of extended bodies. (c) is just nonsense.