Solutions to Exam 1; Phys 100

1. (5 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. (5 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 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. (5 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. (5 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. (5 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. (5 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. (5 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. (5 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. (5 points) You lift an object that weighs 1 N by 1 m. By approximately how much does the object's mass increase?

(a) It does not increase at all

(b) 0.001 kg

(c) 10^{-10} kg

(d) 10^{-17} **kg**

(e) 10^{-23} kg

10. (5 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. (5 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. (5 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. (5 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. (5 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. (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

16. (10 points) In the *Dr Who* clip I showed in class, the science officer says they are on a physically impossible planet, since the planet is outside the event horizon of a black hole but yet it keeps a constant distance to the black hole and is not sucked in. This is wrong! What is a way to keep at a constant distance to a black hole, without violating any laws of physics? Explain.

Answer: The only significant force between the planet and the black hole is gravity. So just like the moon can revolve around the Earth at a roughly constant distance, being attracted toward the Earth, but not falling into the Earth, a planet can orbit around a black hole, provided it is going fast enough.

17. (15 points) Say you are in a rocket blasting off from Earth, headed for the stars. Let's say, to keep the crew comfortable, your acceleration is always equal to the acceleration due to gravity. That is, every second that passes, your speed increases by 9.8 m/s.

(a) How many *years* will it take for you to achieve a speed of one quarter the speed of light, $s = c/4$?

Answer: Since the speed increases by 9.8 m/s every second, it will take

$$\frac{c/4}{9.8\ \text{m/s}^2} = \frac{3 \times 10^8/4}{9.8} = 7.7 \times 10^6\ \text{s}$$

To convert that into years, divide by the number of seconds in a year: $60 \times 60 \times 24 \times 365$. We end up with 0.24 years: just about three months.

(b) If you were also to calculate the amount of energy you'd need to expend to achieve that speed, could you ignore relativity? Explain.

Answer: Yes, we could ignore relativity. At $s = c/4$, we have

$$\gamma = \frac{1}{\sqrt{1 - (\frac{1}{4})^2}} = \sqrt{\frac{16}{15}} = 1.033 \approx 1$$

Since γ is close to 1, relativistic effects are small.

(c) Support your answer to (b) with a calculation. You need to find the percent error you introduce by using the classical kinetic energy, $\frac{1}{2}ms^2$, instead of the relativistic kinetic energy, $(\gamma - 1)mc^2$, for $s = c/4$. Remember, if you're comparing x to a correct value y,

$$\%\ \text{error} = \frac{|x - y|}{y} \times 100\%$$

Answer: Do the calculation, observing that the masses and the c^2's cancel:

$$\%\ \text{error} = \frac{\left|0.033mc^2 - \frac{1}{2}mc^2/4^2\right|}{0.033mc^2} \times 100\% = 4.7\ \%$$

About a 5% error; reasonably small.

18. (15 points) A 1.7 m tall man with a mass of 60 kg is standing on the surface of the Earth.

(a) Calculate the tidal force on him—the difference between the Earth's gravitational force on the bottom of her feet and the force at the top of his head.

Mathematical tip: His height h is much smaller than the Earth's radius r. In that case,

$$\frac{1}{r^2} - \frac{1}{(r+h)^2} \approx \frac{2h}{r^3}$$

Answer: Using the tip, the difference between the forces is

$$Gm_{\text{man}}m_{\text{Earth}}\left[\frac{1}{r^2} - \frac{1}{(r+h)^2}\right] \approx \frac{2hGm_{\text{man}}m_{\text{Earth}}}{r^3} = 3.1 \times 10^{-4}\ \text{N}$$

This is hardly noticeable, as we would expect.

(b) Now calculate how much mass must be packed into a sphere with the same radius of the Earth to get a tidal force that might tear him apart—say, 3000 N. How many solar masses is this?

Answer: The result above is proportional to the mass of the Earth. And only that mass changes for this part of the question. So we need to multiply the Earth's mass by the force ratio, $3000/3.1 \times 10^{-4}$, to get the mass we need to pack into the Earth's radius:

$$\frac{3000}{3.1 \times 10^{-4}} 6 \times 10^{24}\ \text{kg} = 5.8 \times 10^{31}\ \text{kg}$$

If we divide this by the solar mass, we get

$$\frac{5.8 \times 10^{31}}{2 \times 10^{30}} = 29$$

So we need about 29 solar masses. A black hole should do it.

19. (15 points) Compare two possibilities for space travel:

(A) *Star Trek*-style: a large crew of humans and equipment occupying a space craft and rapidly traveling between the stars.

(B) *Fermi paradox*-style: machines with no crew traveling slowly and replicating themselves with material found at their destinations.

Use the physics you have learned (relativity, energy, etc.) to assess which of these possibilities is a more plausible way to travel between the stars.

Answer: **(B)** is much more plausible than **(A)**.

Star Trek-style travel requires moving large masses around—the crew, their equipment, their life support systems. And this has to be done quickly, so they much achieve speeds close to the speed of light. But the energy requirements are immense, since their mass will also increase as they get close to c. You need lots of fuel, and you have to expend the extra energy to bring all that fuel itself up close to c. And then there are problems such as collisions with even dust particles being disastrous at high speeds. **(A)** is an enormously expensive scenario, if even possible.

Fermi paradox-style travel avoids all these problems. A machine can be small, and does not need life support systems. It can function in empty space, with very little energy. And traveling slowly, at much smaller than light speed, avoids relativistic complications. Even if it takes a hundred years for a machine to travel each light year, with self-replication, they can cover a whole galaxy in just millions of years.

20. (15 points) Pick one of the following weird and surprising phenomena: (A) time dilation, (B) length contraction, (C) the big bang, (D) neutron stars, (E) energy conservation.

(a) Explain why this is weird and surprising to you. (There's no set right answer here; I'm just asking you to reflect upon what you have heard about in class.)

Answer: No set answer; it depends on the person answering. I have to grade these on a case-by-case basis, to see if you've given these things some thought.

(b) Say you were not inclined to just take my word in class as a physics professor that this phenomenon is real. What would you demand from me to convince you that it is real? For example, what kind of experiment could you suggest? (I'll be more impressed with more doable experiments.)

Answer: Again, case by case.