Solutions to Exam 1; Phys 100

1. (50 points) Planets actually have elliptical orbits. Consider a planet (black) orbiting around its star (red) in two different locations on its orbit (green).

(a) Draw arrows on the two planet locations indicating the *gravitational force* due to the star on the planet at that location. If the force is stronger at one of the locations, indicate this by making its arrow longer.

Answer: Gravity is an attractive force. The planet will be attracted toward the star. Gravity is also a force that gets weaker the farther apart objects are. So the arrow on the planet location farther from the star should be smaller.

(b) Draw arrows on the two planet locations indicating the *electric force* due to the star on the planet at that location. If the force is stronger at one of the locations, indicate this by making its arrow longer.

Answer: Both the planet and the star are electrically neutral. Therefore there is zero electric force and nothing to draw.

(c) Draw arrows on the two planet locations indicating the *velocity* of the planet. If the speed is faster at one of the locations, indicate this by making its arrow longer.

Explain: (*Hint:* Think of energy conservation. Gravitational energy is larger the farther away gravitationally interacting objects are. What does this imply for kinetic energy, and therefore speed?)

Answer: The velocity direction. is the direction of motion. So the arrows should be tangential to the ellipse.

The total energy of the planet, which is its kinetic pus gravitational energy, is conserved. When the planet is farther away, its gravitational energy is larger. For the total to remain the same, that mean that when it's far, its kinetic energy must be smaller. Since the planet's mass does not change, that can only happen if its speed is smaller. Therefore, the velocity arrow for the far location must be shorter.

(d) Draw arrows on the two planet locations indicating the *acceleration* of the planet. If the acceleration is larger at one of the locations, indicate this by making its arrow longer.

Answer: Total force is mass times acceleration. Gravity is the only force on the planet, so the total force is just the gravity from part (a). Since the mass is the same, the acceleration is proportional to the gravity. This means that the relative size and direction of the arrows should be the same as in (a). You might as well repeat the same drawing.

2. (75 points) You decide to write a science fiction story where a black hole passes close to the Earth, just 0.1 light-years away. Your protagonists get into a spaceship and head toward the black hole, hoping to be the first humans who land on the black hole and return to Earth with rock samples from its surface.

You want the feeling of normal gravity on the spaceship, so the spaceship starts from Earth, at rest, and moves toward the black hole 0.1 light-years away with a constant acceleration equal to the acceleration due to gravity on Earth. At the midpoint of the journey, the spaceship turns around to face in the opposite direction, keeps blasting its engines, and starts to slow down at a rate that is equal to the acceleration due to gravity back on Earth. This makes sure that the spaceship will be at rest when it arrives at its destination. You assume that relativity does not apply.

You then have some of your friends read your story, so they can find physics-related plot mistakes, to save you embarrassment before the story is published.

(a) One friend worries that while the first half of the trip will be fine, with everyone feeling as if they were at normal gravity back on Earth while walking around the floors of the spaceship, after the flip at the halfway point, they will have to walk on the ceilings instead. Is this correct? Explain.

Answer: After the flip, the acceleration will be the same magnitude, and *within the spaceship*, it still will be in the direction of the ceiling. Therefore the floor will push on the passengers' feet exactly the same way in both halves of the trip; nothing will change.

(b) In a physics textbook, you find that for motion starting from rest with constant acceleration, $d = \frac{1}{2}at^2$, where d is the distance traveled, a is the acceleration, and t is the time elapsed to get to d. How long will it take for the spaceship to make it to the halfway point where it flips around? Is this a reasonable amount time in which to set a story?

Answer: You need to solve for the time t; you will end up with

$$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2\frac{1}{2}(0.1)(3\times10^8\,\mathrm{m/s})(365\times24\times60\times60\,\mathrm{s})}{9.8\,\mathrm{m/s^2}}} = 9.83\times10^6\,\mathrm{s} = 0.31\,\mathrm{years}$$

That's a reasonable amount of time for a story.

(c) How long will it take to complete the second half of the journey? (You don't need a calculation here. Just explain your answer.)

Answer: Exactly the same amount of time: 0.31 years. It will take exactly the same amount time to slow down to rest as it took to speed up, since the acceleration magnitude is the same; it just reverses direction.

(d) In your physics book, you also find that $s = at$, where s is the speed. How fast will the spaceship be traveling at the point where it flips around?

Answer: It's a straightforward calculation:

$$s = (9.8\,\mathrm{m/s^2})(9.83 \times 10^6\,\mathrm{s}) = 9.63 \times 10^7\mathrm{m/s}$$

This is fast: $s = 0.32\,c$.

(e) All your calculations assumed that relativity did not apply. Knowing the speed at the halfway point, do you think that was a good assumption or not? (*Hint:* you need to calculate something that tells you whether relativistic effects are important or not.)

Answer: You need to calculate the time dilation factor γ to see if relativity is important. At the halfway point, where the speed relative to Earth is largest,

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{s}{c}\right)^2}} = \frac{1}{\sqrt{1 - (0.32)^2}} = 1.056$$

This γ is not exactly 1, but it is only 5.6% larger than 1. The error introduced into your time calculations by ignoring relativity will be small; it won't affect the story.

(f) Another friend asks if you need to say something about how the black hole was detected from Earth in the first place: maybe tell the story of how astronomers first saw the light from the black hole on a telescope. Is this a good idea? Explain.

Answer: No light can escape from a black hole, so astronomers can have no light from a black hole to detect. Unless the black hole is ripping something else apart and creating light in the process, there will be nothing to see. And in the empty space close to our solar system, there isn't anything to rip apart.

(g) You show the story to a physics major friend, and they tell you that you haven't noticed the biggest physics mistake yet. What might they be talking about?

Answer: *Nothing* escapes from a black hole. The whole premise of landing on a black hole and then *returning* is absurd.

3. (25 points) One of the themes of this course is that everyday common sense is not a good guide to the universe. Describe an example that you have encountered so far where you felt that what you were learning did not make sense to you—you felt it had to be wrong or that your mind was blown. Explain why. Then explain why you trust me (I hope you do) when I tell you that yes, the universe behaves in exactly that way that you think is crazy.

Answer: Answers will individually vary. I'm just looking for some sensible reflection.