Exercises for Unit 7: Astrophysics

Lesson 1: Particle Physics Exercises

1. All visible matter is made up of…?
2. What is a quark?
3. What's the charge on an electron, proton, and neutron?
4. What keeps the quarks together inside a proton?
5. Are free neutrons or protons more stable?
6. What forces are the 79 protons together inside a gold atom feeling?
7. Why does an electron stick around to orbit a nucleus?
8. Where can you find anti-matter on Earth?
9. What's the difference between fusion and fission?
10. Where can you find radiation?

Exercises for Unit 7: Astrophysics

Lesson 2: Astronomy Exercises

1. If a mad scientist pointed his alpha particle gun straight at you, what would be your best defense?

2. Did Pluto get smacked out of existence, or is it still there? What other 'planet' did this happen to?

3. How accurate is the main idea in the 2007 movie "Sunshine", where the mission was to reignite the sun?

4. How do you make a black hole?

5. How can you detect a black hole?

6. What happens if your car zooms at nearly the speed of light and turn on your headlights?

7. What's your favorite part about Jupiter?

8. Which planet is NOW your favorite (after listening to the astronomy teleclass)?

9. What happened to the stars in the slideshow/teleclass?

10. Which stars don't twinkle?

11. How many moons can you see with binoculars?

Exercises for Unit 7: Astrophysics

Lesson 3: Relativity

1. What's wrong with the statement "moving clocks run slow"? Can you find this or a similar "relativistically incorrect" statement in a book on relativity?
2. Suppose two triplets leave Earth at the same time and undertake roundtrip space journeys of identical length and at the same speed but in opposite directions. When they return, will they be the same age or will one be older? How will their ages compare with their third sibling, who stayed at home on Earth?
3. In 1999, scientists discovered a planetary system orbiting a star 44 light-years from Earth. How far into the future could you travel by taking a high-speed trip to this star and returning immediately back to Earth? Under what conditions would you achieve this maximum future travel? How long would you judge the trip to take?
4. Suppose the twin in the spaceship traveled at 0.6c instead of 0.8c. By how much would the twins' ages differ when the traveling twin returns to Earth?
5. A famous "paradox" of relativity is the following: A high-speed runner carries a 10-foot-long pole toward a barn that is 10 feet long and has doors open at both ends. The runner is going so fast that, from the point of view of the farmer who owns the barn, the pole is only 5 feet long. Clearly, the farmer can close both barn doors and trap the runner in the barn. But to the runner, the pole is 10 feet long and the barn, rushing toward the runner, is only 5 feet long. So clearly the runner can't be in the barn with both doors closed. Can you resolve the paradox, using the fact that events simultaneous in one reference frame aren't simultaneous in another? (By the way, the speed required here is 0.866c.)
6. Right now it's "the present," but is it "the present" everywhere? Explain your answer.
7. What's wrong with the definition "the past consists of those events that have already happened"?

8. You throw a bunch of subatomic particles into a closed box, the walls of which block the passage of matter but not energy. Must the number of particles in the box remain the same? Explain.
9. You drop a large rock and a small rock. Because of its larger mass, the gravitational force on the larger rock is greater. Why doesn't the larger rock fall with greater acceleration?
10. An airplane flying from San Francisco to Tokyo first heads north toward the coast of Alaska. Why? How is this analogous to what happens in general relativity's description of gravity?
11. In special relativity, we stressed that time dilation is reciprocal: When we're moving relative to each other, I see your clock running slow, and you see mine running slow. Now we have gravitational time dilation in general relativity: If you're closer to Earth or another gravitating body than I am, I see your clock running slow. Do you expect this effect to be reciprocal too, or will you see my clock running fast?
12. Gravity seems a pretty formidable force if you're trying to lift a heavy object or scale a cliff. In what sense, though, is gravity on Earth (and indeed throughout our solar system) weak?
13. If the Earth suddenly shrank to become a black hole, with no change in mass, what would happen to the moon in its circular orbit?
14. If you were falling into a black hole and looked at your watch, would you notice time "slowing down"? Justify your answer using basic principles of relativity.
15. You are on a jet flying 600 mph through calm air. You open a bag of peanuts while the slight attendant pours your tea into a cup on your tray. Why do you suppose that you don't have to take into account the jet's motion when the tea and peanuts travel at 600 mph?
16. Many people think astronauts in space are weightless because there's no gravity in space. How would Newton argue against this?
17. Maxwell's equations predict the existence of EM waves (light) going at speed c… but with respect to what? Relative to what?

Answers to Particle Physics Exercises

1. All visible matter is made up of electrons, protons and neutrons.
2. A quark makes up the nucleus of an atom. A proton is made up of two up quarks and one down quark. A neutron is made up of one up quark and two down quarks.
3. An electron has a negative charge, a proton has a positive charge, and a neutron has no charge.
4. The gluons hold the quarks together to form neutrons and protons.
5. Free neutrons flip into a more stable proton within 15 minutes.
6. The protons are feeling an electromagnetic 'repulsive push' force, as they are all the same charge. (Think of how two north sides of a magnet don't like each other.) However, the residual strong force is much stronger at the atomic scale and overcomes the repulsive force and pions bind the protons together.
7. An electron has a negative charge, which is attracted to the positive charge of the protons inside the nucleus.
8. A PET scan is a way of imaging using positrons. Patients ingest anti-matter and a machine takes pictures of the puffs of energy given off by the colliding matter (electrons) and anti-matter (positrons).
9. Fission is splitting atoms apart, and fusion is smooshing them together. An atomic bomb uses fission, and the sun uses fusion.
10. When an atom spontaneously undergoes fission (splitting), it's called fission. Uranium 235 is an example of an element that does this.

Answers to Astronomy Exercises

1. Hold up a sheet of paper between you and the gun.
2. Pluto was once considered one of the planets, but in recent years was demoted to 'dwarf planet' status and is now part of the Kuiper Belt Objects. Ceres underwent the same sort of thing in the 1800s, and now belongs to the asteroid belt between Mars and Jupiter.
3. The sun is not on fire, like a candle. You can't blow it out or reignite it. The nuclear reactions deep in the core transforms 600 million tons per second of hydrogen into helium using a chemical processes called the proton-proton chain.
4. When a star uses up its fuel, the way it dies depends on how massive it was to begin with. Large stars can go supernova and collapse in on themselves indefinitely, forever.
5. By looking at oddball things that happen around the black hole. For example, light getting distorted and forming streaks and multiple images where there should be only one object, or watching an object get yanked about without anything visible around to the pulling, x-rays and gamma ray jets, or the accretion disk ring lighting up.
6. You would see white headlights coming from the front of your car, but a friend sitting on the ground miles ahead of you, watching you race toward them would see you turn on blue headlights.
7. Take your pick: MASERs shooting out of the poles of Jupiter; the way Jupiter shocks Io with 3 million amps every time it crosses its magnetic fields; Io belching itself inside-out; needing windshield wipers if you stay in orbit around Io… the list goes on and on.
8. Most people settle their focus on Neptune and/or Venus after the teleclass.
9. Barnard 68 is an example of a dark nebula. It absorbs all light (energy) and is the coldest spot we've ever found out there in the universe. The stars are still there, but behind the dark cloud.
10. Planets don't twinkle, but stars do. It's an easy way to spot Jupiter, Saturn, Venus, and Mercury.
11. You can see our Moon, four moons of Jupiter (Ganymede, Io, Europe, and Callisto), and four of Saturn.

Answers to Relativity Exercises

1. What's wrong with the statement "moving clocks run slow"? Can you find this or a similar "relativistically incorrect" statement in a book on relativity? This implies that there is something special about one reference frame over another. Relativity states that all reference frames are equal.

2. Suppose two triplets leave Earth at the same time and undertake roundtrip space journeys of identical length and at the same speed but in opposite directions. When they return, will they be the same age or will one be older? How will their ages compare with their third sibling, who stayed at home on Earth? The two will return the same age but arrive younger than the Earthbound triplet.

3. In 1999, scientists discovered a planetary system orbiting a star 44 light-years from Earth. How far into the future could you travel by taking a high-speed trip to this star and returning immediately back to Earth? Under what conditions would you achieve this maximum future travel? How long would you judge the trip to take? The traveling person could take only minutes or second to make the trip, and an Earthbound observer would see the trip as taking just over 88 years. The traveler would arrive just over 88 years into the future at the same age as they left.

4. Suppose the twin in the spaceship traveled at 0.6c instead of 0.8c. By how much would the twins' ages differ when the traveling twin returns to Earth? The traveling twin would have taken 20 years instead of 15 years for the trip, so their age difference would be only five years upon return.

5. A famous "paradox" of relativity is the following: A high-speed runner carries a 10-foot-long pole toward a barn that is 10 feet long and has doors open at both ends. The runner is going so fast that, from the point of view of the farmer who owns the barn, the pole is only 5 feet long. Clearly, the farmer can close both barn doors and trap the runner in the barn. But to the runner, the pole is 10 feet long and the barn, rushing toward the runner, is only 5 feet long. So clearly the runner can't be in the barn with both doors closed. Can you resolve the paradox, using the fact that events simultaneous in one reference frame aren't simultaneous

in another? (By the way, the speed required here is 0.866c.) From the runner's point of view, the pole will reach the second door before the pole clears the first door. From the farmer's point of view, the pole will reach the second door after it clears the first door. The events are not in the same order for both viewpoints. Yet both are right. These events are not simultaneous.

6. Right now it's "the present," but is it "the present" everywhere? Explain your answer. No. It is elsewhere in events that are too far away to influence any events occurring right now.

7. What's wrong with the definition "the past consists of those events that have already happened"? Who's past? Since events can be different depending on your viewpoint, my past may not be the same as yours. You might see two lights switch on at the same time whereas I saw one light up before the other; hence our past experiences are different. Yet both are correct.

8. You throw a bunch of subatomic particles into a closed box, the walls of which block the passage of matter but not energy. Must the number of particles in the box remain the same? Explain. No. If two particles combine and annihilate each other (a positron and electron, for example), then the number of particles will decrease but the amount of energy generated may escape.

9. You drop a large rock and a small rock. Because of its larger mass, the gravitational force on the larger rock is greater. Why doesn't the larger rock fall with greater acceleration? The larger rock has more inertia (resistance to motion) and takes longer to accelerate. And it probably is larger and will have more air drag as well, although this problem didn't mention this effect.

10. An airplane flying from San Francisco to Tokyo first heads north toward the coast of Alaska. Why? How is this analogous to what happens in general relativity's description of gravity? The shortest distance on a sphere is the Great Circle Distance. Gravity curves spacetime and objects will now travel along a curve that takes the shortest possible line along this curved path.

11. In special relativity, we stressed that time dilation is reciprocal: When we're moving relative to each other, I see your clock running slow, and you see mine running slow. Now we have gravitational time dilation in general relativity: If you're closer to Earth or another gravitating body than I am, I see your clock running slow. Do you expect this effect to be reciprocal too, or will you see my clock running fast? I will see your clock running at a different rate than mine due to gravitational time dilation.

12. Gravity seems a pretty formidable force if you're trying to lift a heavy object or scale a cliff. In what sense, though, is gravity on Earth (and indeed throughout our solar system) weak? The escape speed is very slow compared to the speed of light.

13. If the Earth suddenly shrank to become a black hole, with no change in mass, what would happen to the moon in its circular orbit? Nothing. The moon does not care what shape the Earth is. It's only responding to the mass of the Earth.

14. If you were falling into a black hole and looked at your watch, would you notice time "slowing down"? Justify your answer using basic principles of relativity. No, you would see the clock ticking by as usual as you passed the event horizon and drifted in for awhile, until you were stretched thin from the gravitational forces of the black hole and shredded at the subatomic level.

15. You are on a jet flying 600 mph through calm air. You open a bag of peanuts while the slight attendant pours your tea into a cup on your tray. Why do you suppose that you don't have to take into account the jet's motion when the tea and peanuts travel at 600 mph? My reference frame is in uniform motion (constant speed and in a straight line) and thus just as good as the stationary observer at the airport. I observe nothing unusual going on in my reference frame. The laws of physics apply to my viewpoint just as well as any other reference frame in uniform motion.

16. Many people think astronauts in space are weightless because there's no gravity in space. How would Newton argue against this? There IS gravity in space, otherwise the planets would not orbit around the sun. The weightless the astronaut feels has to do with the orbit he takes around the Earth – the astronaut is not just 'sitting' out there in orbit, he's traveling about 5 miles per second around the Earth, which keeps

him in orbit. His travels at the same rate that the Earth is curving away from him. To simulate artificial gravity, he would need to be in a rotating space station.

17. Maxwell's equations predict the existence of EM waves (light) going at speed c… but with respect to what? Relative to what? Speed c is relative to all observers.