## 14.8 Appendix H: Qualitative relativity questions

1. Is there such a thing as a perfectly rigid body?

   **Answer:** No. Since information can move no faster than the speed of light, it takes time for the atoms in the body to communicate with each other. If you push on one end of a rod, then the other end will not move right away.

2. Moving clocks run slow. Does this result have anything to do with the time it takes light to travel from the clock to your eye?

   **Answer:** No. When we talk about how fast a clock is running in a given frame, we are referring to what the clock actually reads in that frame. It will of course take time for the light from the clock to reach an observer's eye, but it is understood that the observer subtracts off this transit time in order to calculate the time at which the clock actually shows a particular reading.

   Likewise, other relativistic effects, such as length contraction and loss of simultaneity, have nothing to do with the time it takes light to reach your eye. They deal only with what really *is*, in your frame.

3. Does time dilation depend on whether a clock is moving across your vision or directly away from you?

   **Answer:** No. A moving clock runs slow, no matter which way it is moving.

4. Does the special-relativistic time dilation depend on the acceleration of the moving clock?

   **Answer:** No. The time-dilation factor is $\gamma = 1/\sqrt{1 - v^2/c^2}$, which does not depend on $a$. The only relevant quantity is the $v$ at a given instant. It doesn't matter if $v$ is changing.

   Of course, if *you* are accelerating, then you can't naively apply the results of special relativity. (To do things correctly, it is perhaps easiest to think in terms of general relativity. But GR is actually not required; see Chapter 13 for a discussion of these issues.) But as long as you represent an inertial frame, then the clock you are viewing can undergo whatever motion it wants, and you will observe it running slow by the simple factor, $\gamma$.

5. Someone says, "A stick that is length-contracted isn't *really* shorter, it just *looks* shorter." Do you agree?

   **Answer:** Hopefully not. The stick really *is* shorter in your frame. Length contraction has nothing to do with how things look. It has to do with where the ends of the stick are at simultaneous times in your frame. (That is, after all, how you measure the length of something.) At a given instant in time (in your frame), the distance between the ends of the stick is indeed less than the proper length of the stick.

6. Consider a stick that moves in the direction in which it points. Does its length contraction depend on whether this direction is across your vision or directly away from you?

**Answer:** No. The stick is length-contracted in both cases. Of course, if you look at the stick in the latter case, then all you will see is the end, which will just be a dot. But the stick is indeed shorter in your reference frame.

7. A mirror moves toward you at speed $v$. You shine a light towards it and the light beam bounces back at you. What is the speed of the reflected beam?

   **Answer:** The speed is $c$, as always. You will observe the light having a higher frequency, due to the Doppler effect. But the speed is still $c$.

8. In relativity, the order of two events in one frame may be reversed in another frame. Does this imply that there exists a frame in which I get off a bus before I get on it?

   **Answer:** No. The order of two events can be reversed in another frame only if the events are spacelike separated. That is, if $\Delta x > c\Delta t$ (in other words, the events are too far apart for even light to get from one to the other). The two relevant events here (getting on the bus, and getting off the bus) are not spacelike separated, because the bus travels at a speed less than $c$, of course. They are timelike separated. Therefore, in all frames it is the case that I get off the bus after I get on it.

   There would be causality problems if there existed a frame in which I got off the bus before I got on it. If I break my ankle getting off a bus, then I wouldn't be able to make the fast dash that I made to catch the bus is the first place, in which case I wouldn't have the opportunity to break my ankle getting off the bus, in which case I could have made the fast dash to catch the bus and get on, and, well, you get the idea.

9. You are in a spaceship sailing along in outer space. Is there any way you can measure your speed without looking outside?

   **Answer:** There are two points to be made here. First, the question is meaningless, because absolute speed does not exist. The spaceship does not have a speed; it only has a speed relative to something else.

   Second, even if the question asked for the speed with respect to, say, a piece of stellar dust, the answer would be "no." Uniform speed is not measurable from within the spaceship. Acceleration, on the other hand, is measurable (assuming there is no gravity around to confuse it with).

10. If you move at the speed of light, what shape does the universe take in your frame?

    **Answer:** The question is meaningless, because it is impossible for you to move at the speed of light. A meaningful question to ask is: What shape does the universe take if you move at a speed very close to $c$? The answer is that in your frame everything would be squashed along the direction of your motion. Any given region of the universe would be squashed down to a pancake.

11. Two objects fly toward you, one from the east with speed $u$, and the other from the west with speed $v$. Is it correct that their relative speed, as measured by you, is $u + v$? Or should you use the velocity-addition formula, $V = (u+v)/(1+uv/c^2)$? Is it possible for their relative speed, as measured by you, to exceed $c$?

    **Answer:** Yes, no, yes, to the three questions. It is legal to simply add the two speeds to obtain $u + v$. There is no need to use the velocity-addition formula, because both speeds here are measured with respect to the *same thing*, namely you. It is perfectly legal for the result to be greater than $c$ (but it must be less than $2c$).

    You need to use the velocity-addition formula when, for example, you are given the speed of a ball with respect to a train, and also the speed of the train with respect to the ground, and your goal is to find the speed of the ball with respect to the ground. The point is that now the two given speeds are measured with respect to *different* things, namely the train and the ground.

12. Two clocks at the ends of a train are synchronized with respect to the train. If the train moves past you, which clock shows the higher time?

    **Answer:** The rear clock shows the higher time. It shows $Lv/c^2$ more than the front clock, where $L$ is the proper length of the train.

13. A train moves at speed $4c/5$. A clock is thrown from the back of the train to the front. As measured in the ground frame, the time of flight is 1 second. Is the following reasoning correct? "The $\gamma$-factor between the train and the ground is $\gamma = 1/\sqrt{1-(4/5)^2} = 5/3$. And since moving clocks run slow, the time elapsed on the clock during the flight is 3/5 of a second."

    **Answer:** No. It is incorrect, because the time-dilation result holds only for two events that happen at the *same place* in the relevant reference frame (the train, here). The clock moves with respect to the train, so the above reasoning is not correct.

    Another way of seeing why it must be incorrect is the following. A certainly valid way to calculate the clock's elapsed time is to find the speed of the clock with respect to the ground (more information would have to be given to determine this), and to then apply time dilation with the associated $\gamma$-factor to arrive at the answer of $1/\gamma$. Since the clock's $v$ is definitely not $4c/5$, the correct answer is definitely not 3/5 s.

14. Person $A$ chases person $B$. As measured in the ground frame, they have speeds $4c/5$ and $3c/5$, respectively. If they start a distance $L$ apart (as measured in the ground frame), how much time will it take (as measured in the ground frame) for $A$ to catch $B$?

    **Answer:** As measured in the ground frame, the relative speed is $4c/5 - 3c/5 = c/5$. Person $A$ must close the initial gap of $L$, so the time it takes is $L/(c/5) = 5L/c$. There is no need to use any fancy velocity-addition or length-contraction formulas, because all quantities in this problem are measured with respect to the *same* frame. So it quickly reduces to a simple "(rate)(time) = (distance)" problem.

15. Is the "the speed of light is the same in all inertial frames" postulate really necessary? That is, is it not already implied by the "the laws of physics are the same in all inertial frames"?

    **Answer:** Yes, it is necessary. It turns out that nearly all the results in relativity can be deduced by using only the "the laws of physics are the same in all inertial frames" postulate. What you can find (with some work) is that there is some limiting speed (which may or may not be infinite). But you still have to postulate that light is the thing that moves with this speed. See Section 10.8.

16. Imagine closing a very large pair of scissors. It is quite possible for the point of intersection of the blades to move faster than the speed of light. Does this violate anything in relativity?

    **Answer:** No. If the angle between the blades is small enough, then the tips of the blades (and all the other atoms in the scissors) can move at a speed well below $c$, while the intersection point moves faster than $c$. But this does not violate anything in relativity. The intersection point is not an actual object, so there is nothing wrong with it moving faster than $c$.

    We should check that this setup cannot be used to send a signal down the scissors at a speed faster than $c$. Since there is no such thing as a rigid body, it is impossible to get the far end of the scissors to move right away, when you apply a force with your hand. The scissors would have to already be moving, in which case the motion is independent of any decision you make at the handle to change the motion of the blades.

17. Two twins travel away from each other at relativistic speed. The time-dilation result from relativity says that each twin sees the other's clock running slow, so each says the other has aged less. How would you reply to someone who asks, "But which twin really *is* younger?"

    **Answer:** It makes no sense to ask which twin really is younger, because the two twins aren't in the same reference frame; they are using different coordinates to measure time. It's as silly as having two people run away from each other into the distance (so that each person sees the other become very small), and then asking: Who is really smaller?

18. The momentum of an object with mass $m$ and speed $v$ is $p = \gamma mv$. "A photon has zero mass, so it should have zero momentum." Correct or incorrect?

    **Answer:** Incorrect. True, $m$ is zero, but the $\gamma$ factor is infinite because $v = c$. Infinity times zero is undefined. A photon does indeed have momentum, and it equals $E/c$ (which equals $h\nu/c$, where $\nu$ is the frequency of the light).

19. It is not necessary to postulate the impossibility of accelerating an object to speed $c$. It follows as a consequence of the relativistic form of energy. Explain.

**Answer:** $E = \gamma mc^2$, so if $v = c$ then $\gamma = \infty$, and the object must have an infinite amount of energy (unless $m = 0$, as for a photon). All the energy in the universe, let alone all the king's horses and all the king's men, can't accelerate something to speed $c$.