Study Guide: *Simply Einstein: Relativity Demystified*

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General Advice and Timeline

Throughout this book, there will be many ideas and concepts which you will want to think about, talk about, find out more about. You should develop a practice of reading which includes carrying pen and paper along so that you can write down questions you have, words you want to look up, concepts you want to discuss further, and other notations.

Another important thing to build into your practice of reading this book (and other books like it) is to give yourself the opportunity to focus. This means that you should attempt to read it in a place that is free of distractions; you should go slowly, allowing yourself time to think about each paragraph after you read it; and you should not hesitate to re-read sections which seem either confusing or eye-opening. The reading assignments are short by design. Don't rush through them, and don't leave them for the last minute. Read it once early in the week and again later in the week. This material is *not obvious*. Set aside the time to let it sink in.

We will be covering only chapters 1-13 of the book, and we will be reading chapter 13 out of order. The general timeline for reading the book is as follows:

- During week 1, read and discuss the preface and chapter 2; read chapters 3 and 4.

- During week 2, discuss chapters 3 and 4; read chapters 5 - 7.

- During week 3, discuss chapters 5 - 7; read chapter 8.

- During week 4, discuss chapter 8; read chapters 9 and 13.

- During week 5, discuss chapters 9 and 13.

- During week 6, continue discussing chapters 9 and 13; read chapter 10.

- During week 7, discuss chapter 10; read chapter 11.

- During week 8, discuss chapter 11; read chapter 12.

- During week 9, discuss chapter 12.

1 The Self-Creating Universe and Other Absurdities

1.1 Before you read

This first chapter is a collage of far-out physics. Wolfson is trying to get the reader to 'think outside the box' as well as to provide some motivation for the material of the book.

For our purposes, the only section you really need to read is 'Escape to the Future.' Read the rest of the chapter, but don't worry about understanding it. None of it is meant to be digested at this point. Treat it as an appetizer. The main course is still coming.

1.2 As you read

Ask yourself, as you read the 'Escape to the Future' section, what we generally mean by 'time travel' and it means to 'jump into the future.' Does what Wolfson describes fit with these ideas? Hopefully the readings and your thoughts will lead you to the question "Whose future?"

1.3 After you read

Since this is an introductory chapter, it should raise more questions than it answers. There is no need at this point to have all the answers, but you should feel free to investigate the questions further. Take a little time to write out what ideas you want to investigate. Jot down the things which seem most improbable or confusing. Let your curiosity overcome any skepticism you have at this point. Suspend your disbelief and play with the ideas. This will be very important as we move further into discussions of what we take to be *true but not obvious.*

2 Tennis, Tea, and Time Travel

2.1 Before you read

The ideas of this chapter are simple, but they are very important. The rest of the book will continually refer to both the ideas and the specific scenarios discussed here. So take the time to think through the scenarios carefully. Be sure to note areas where you are the least bit hesitant to accept Wolfson's claims or where you are at all unsure that you understand his point. Bring these areas up for discussion with your study group, your seminar, and the class as a whole.

2.2 As you read

As you are reading the scenarios of this chapter, test your own beliefs against the ideas presented by Wolfson.

1. Do you agree with what is presented as 'common sense'?

2. Are there any conditions or situations Wolfson is ignoring?

3. Why does he take such care to construct the scenarios the way he does?

2.3 After you read

1. What is the point of the discussion at the end of the chapter about crawling around as a baby and being a young child?

2. List some things which would be different on a smoothly moving cruise ship compared to standing 'on dry land.'

3. If you throw a tennis ball straight up, it slows down, changes direction at the top of its path, and then speeds up on the way down. What might be happening if the ball doesn't do this, even when you throw it straight up?

4. Under what conditions might you expect a microwave to work differently?

5. Summarize the theory of relativity in one sentence.

3 Moving Heaven and Earth

3.1 Before you read

As Wolfson clearly states in the introductory paragraphs of this chapter, the point of this chapter is to give the reader some historical background about the developments which have led to our current conceptions concerning the physical world. It is important to read this chapter with that purpose in mind. It is not the intent of the book, nor the intent of this class, to achieve deep understanding of the ideas of Copernicus, Galileo, Kepler, or Newton. But it is very valuable to have a superficial understanding of these ideas in order to appreciate both what is so important about Einstein's formulation of the theory of relativity and why his ideas were considered revolutionary. That said, the concepts introduced in this chapter are not that difficult to understand. The most difficult part really is to put yourself in the mindset of the time.

3.2 As you read

As you read each section, try to put yourself in the mindset of the time. Imagine that you lived before the time of Galileo. Would you think of Moon and Sun as similar to Earth or distinctly different? How would the ideas of Galileo and Copernicus strike you? And even later, in Newton's time, why would you believe that Sun, Moon, and stars obeyed the same rules as those that apply to objects on Earth?

This chapter has several terms which may be new to you or which may be used in a more technical sense than you are used to. Be sure to make a note of any such terms and take the time later to discuss the ideas with others so you can practice using the terms properly.

3.3 After you read

1. Prior to Galileo, the 'natural state' of motion was either rest (for objects on Earth) or circular motion (for celestial objects). Relative to what were both of these states of motion measured?

2. Which ideas of Copernicus, Galileo, Kepler, and Newton helped call into question the 'special place' of Earth in the universe? How do they change the picture of the 'natural state' of motion for Earthly and celestial objects?

3. What is 'uniform motion'?

4. State the principle of Galilean relativity in a simple sentence. How is this different from the general statement of the theory of relativity in chapter 2?

4 Let There Be Light

4.1 Before you read

This chapter is another bit of historical perspective. However, the concepts of waves and electromagnetism are likely much less familiar to you than those covered in chapter 3. So you will need to allow yourself more time to work through this chapter. Again, putting yourself in the mindset of the time is helpful, but even more important is getting a good grasp of the terminology.

4.2 As you read

Keep in mind, throughout the whole chapter, that the reason this material is important is because it is dealing with stuff which does not fit well with the Galilean and Newtonian ideas of chapter 2. At first, there doesn't seem to be much conflict between the idea of waves and the ideas of Galileo and Newton. But as chapter 5 will show, there is a strange conflict that arises when the waves are electromagnetic waves.

4.2.1 Waves

To understand electromagnetic waves (which we cannot see), it is helpful to begin by looking more closely at more familiar waves like water waves and 'the wave' at a sports stadium. Sound, too, is a wave that we cannot see, but it is not too difficult to imagine when you think about the molecular level of the medium through which the sound travels. As sound moves through air, groups of air molecules 'compress' and 'expand' in a very predictable and understandable way. Take the time to work it out for yourself. What would it look like if you could see air molecules as different sounds (loud and soft, high and low pitches) traveled by? In other words, if Fig. 4.1 were a movie rather than a still photograph, how would it change over time?

4.2.2 Light: Waves or Particles?

It is not essential to understand all the evidence presented in this section. What is important is to know that there was very good evidence at the time of Newton that light had 'wave-like' properties – that light behaves like it is made of waves. That evidence is still convincing today, and physicists have not come up with any better way to explain that evidence other than to say that light has 'wave-like' properties.

4.2.3 Electricity and Magnetism

You are probably familiar with both electricity and magnetism, at least superficially. Magnets stick to magnetic things (iron, nickel, and cobalt). Electricity flows through metal wires and lights up light bulbs. Static electricity can make your hair stand up and make things stick together. All of these concepts are fun to investigate further, but the important point of this section of the book is the relation between electricity and magnetism. Magnetism is caused by moving electrons! And moving magnets can cause electricity to flow. This is, in fact, how the electricity lighting up your light bulbs was 'created' – by moving magnets near metal wires. This relationship between electricity and magnetism was discovered in the early to mid 1800s and was the hot area of research through the rest of that century. It is important to note this time period in relation to 1905, the year Einstein published his paper on special relativity.

4.2.4 Fields

This section may seem confusing and easy to skim/skip, but don't be fooled. It is very important to get at least a superficial grasp of the concept of a field. The most important paragraph of this section is the last one. Make sure you understand why the question asked there is important and why the answer given is generally more 'pleasing' than the 'action at a distance' answer proposed earlier in the section.

4.2.5 Electromagnetic Fields

Even if you have the concept of a field, grasping electromagnetic fields can be a stretch. Wolfson does a good job of using gravitational fields first and moving to electromagnetic fields by analogy. But it is not necessary to fully grasp how electromagnetic fields work. What is important is the concept of interaction between electric and magnetic fields. This is essentially a restatement of the connection between electricity and magnetism, and it leads directly to the idea of an electromagnetic wave as introduced in the next section of the chapter.

4.2.6 Electromagnetic Waves

This section is the focal point of the chapter in that all the preceding sections contained preliminary information needed to understand the idea of an electromagnetic wave and the few sections which follow explore the importance of electromagnetic waves. This section is very short, but very important.

4.2.7   Let There Be Light

This section is easy but significant. Light travels at the same speed as an electromagnetic wave; therefore it is reasonable to believe the light *is* an electromagnetic wave.

4.2.8   Making Electromagnetic Waves

This section is not essential for the big picture, but it isn't that hard to grasp. Moving electrons back and forth creates a changing electric field. Changing electric fields create changing magnetic fields. Changing magnetic fields create changing electric fields. This interaction continues and propagates through space as and electromagnetic wave.

4.2.9   A Brief History of Physics

So now we have Newtonian mechanics (and the principle of Galilean relativity) and electromagnetism. Are they compatible? That is the question for the next chapter.

4.3   After you read

1. What is a wave?

2. Is it reasonable to ask, 'Speed relative to what?' when someone tells you the speed of a wave? What will the answer generally be?

3. List a couple reasons why we believe light is a wave. What evidence do we have that light is an electromagnetic wave?

4. How is the idea of 'field' introduced in this chapter like a 'force field' in a science fiction story?

5. Explain briefly how electric and magnetic fields can interact to create an electromagnetic wave.

6. What is the speed of light (and other electromagnetic waves) in a vacuum? Give your answer in either meters per second or kilometers per second.

7. What would your answer be if someone asked you 'Speed relative to what?' about the speed of light?

5 Ether Dreams

5.1 Before you read

This chapter has some interesting details, but none of them are essential, so don't get bogged down in the details. Keep the overall questions in mind: "The speed of light relative to what?" and "If there is an ether, how can we detect it?" Again, it is helpful to put yourself in the mindset of the time period. Wolfson attempts, over and over, to get you to see that the idea of an 'ether' was not as unreasonable then as it seems today.

5.2 As you read

You may feel like Wolfson is rather repetitive in this chapter, and he is. The repetition is meant for emphasis, so be sure you understand what he is emphasizing, and don't let the repetition turn you off.

Make sure you understand fully all of the issues presented in the final section of this chapter (Wrap-up: Physics at 1880). If you have all this down, you have the perspective necessary to see the importance of the next two chapters.

5.3 After you read

1. Why did scientists around 1880 believe that there must be an 'ether'?

2. What makes it difficult to believe that Earth is motionless relative to the 'ether'?

3. Do you have any ideas for ways to detect Earth's motion through the 'ether'?

4. What other alternatives are there if you reject the idea of an 'ether'? Specifically, 'relative to what' do you measure the speed of light if there is no 'ether'?

5. What is the meaning of the word 'ether' to non-scientific people? How about 'ethereal'?

6 Crisis in Physics

6.1 Before you read

This chapter has one simple purpose – to give an overview of one of the most important experiments in physics. The reason this experiment is so important should be obvious in light of the context which Wolfson has provided in the previous chapters. The Michelson-Morley experiment finally made measurements that were precise enough to rule out the ether. The only way to accept the results of the Michelson-Morley experiment and still believe in the ether is to come up with some other "additional hypothesis" like the Lorentz-Fitzgerald contraction mentioned at the end of the chapter. This type of additional hypothesis is usually frowned upon in physics, and science in general, because it does not satisfy the goal of simplicity. The simple result of the Michelson-Morley experiment is that there is no ether.

6.2 As you read

As you read this chapter, keep in mind that the goal is to familiarize you with the setup of the experiment so that you are in a place where you can accept the result. If there are parts of the setup of the experiment you do not understand, that may be okay, as long as you are willing to accept the result of the experiment.

On the other hand, if there are specific parts of the experiment which you want to have explained further, write down the specific question that you have and bring it up with your study group and in class.

6.3 After you read

1. Why does the Michelson-Morley experiment involve perpendicular beams of light?

2. What causes the interference pattern (the light and dark bands in the image at the bottom of figure 6.2) in the Michelson-Morley experiment?

3. Why did Michelson and Morley have to rotate their apparatus as part of the experiement?

4. What did Michelson and Morley expect to see when they rotated their apparatus? What did Michelson and Morley actually see when they rotated their apparatus?

5. What do Michelson and Morley's observations imply about the speed of light along perpendicular paths? And what does that imply about the ether given the orbital speed of Earth?

6. What does "ad hoc" mean in relation to a scientific hypothesis? And how does this relate to the Lorentz-Fitzgerald contraction mentioned at the end of the chapter?

7 Einstein to the Rescue

7.1 Before you read

Wolfson does a nice job of keeping this chapter very short and relatively simple. The main thing you should remember is that Maxwell's equations are laws of physics and that they contain a single value for the speed of light in a vacuum. Maxwell's equations make no reference to any particular reference frame. In other words, nothing about Maxwell's equations looks any different to an observer on the Sun than to an observer on Earth. But the observer on the Sun is moving at a different speed than the observer on Earth! Wolfson has already set you up to believe that relative motion shouldn't make any difference for the laws of physics – balls still bounce the same in tennis and still follow the same trajectory when you thrown them straight up. So you are tempted to accept quite easily the claim that Maxwell's equations should be the same, too.

So why did it take "an Einstein" to suggest it? Why was it considered such an outrageous idea to suggest that Maxwell's equations of electromagnetism were just like Newtonian mechanics in that they were the same in all reference frames? The only reason this is outrageous is that Maxwell's equations contain a prediction for the speed of light. So to suggest that Maxwell's equations are the same in all reference frames is to suggest that the speed of light is the same in all reference frames, and that is not at all what we expect of 'speed.' When two observers are moving relative to each other, we expect speed to be one of the things that they *disagree* about. What Einstein suggests is that the speed of any particular beam of light is one of the things that they will *agree* about!

7.2 As you read

Hopefully, this chapter is an easy read. But again, keep notes of any questions that you have and bring them to your study group and to the class.

7.3 After you read

1. How is the statement of Einstein's special theory of relativity different from the one-sentence statement of Galilean relativity discussed in chapter 3? How does this change the status of electromagnetism from what it was prior to Einstein?

2. What is "special" about special relativity?

3. Relative to what is the speed of light measured according to Einstein?

8 Stretching Time

8.1 Before you read

This chapter introduces the first real consequences of special relativity. Be prepared to think. Take each section one at a time and make sure you get it before you move on. Open your mind to the ideas being presented. They may not make sense at first, but suspend your disbelief for a bit. Go with it, and see where it takes you.

8.2 As you read

It is possible, as you read this chapter, that you will begin to think that Wolfson is going on and on about nothing. But I assure you that he knows what he is doing. He is emphasizing exactly what needs to be emphasized. Don't rush through it. Be prepared to stop and think at any point. Ask yourself, "Why is he saying this in this way? What is he trying to emphasize?"

8.2.1 Measuring the Speed of Light

Although Wolfson may sound a bit tedious in this section, he has a point. Read through the entire example and make sure you understand what he is saying *and* why he is saying it. One thing to notice is that all of the observers are looking at the same beam of light. Why is this important?

8.2.2 A [False] Analogy with Sound

This is a great little section to get you to think about how light is different from all other waves. Light does not need a medium, therefore there is no medium to use to measure light's speed. The waves with which we are more familiar like sound waves and water waves have a definite medium that we use to measure the speed of the waves. So what are we left with for light? Well, one easy way out is to measure the speed of light relative to yourself. And relativity suggests this is okay and that every observer who does that will get the same value for the speed of any particular beam of light, even if the observers are moving relative to each other!

8.2.3 Being Relativistically Correct

This section is very important. Again, Wolfson may sound tedious, but there is a good reason for his repetition. It is very important that you understand the idea that no uniformly moving observer

is "privileged." It is only relative motion that matters. Practice using the proper "way of speaking" when you discuss things with your study group, and try to catch people in class (even the faculty) when they are not "being relativistically correct."

8.2.4 Space and Time are Relative

Again, Wolfson does a very good job emphasizing the right things in this section. It is important to understand that to suggest that one person's instruments are "wrong" is to imply that some other person's instruments are "right." But this would be just the privileged position that we have ruled out. Everyone is using instruments which, to them, appear to be perfectly right. But if they look at each other's instruments, they will find differences.

8.2.5 Sense and Common Sense

This section covers what I always say about relativity – it isn't a mathematically difficult concept; it is just conceptually difficult because it goes against our common sense. It is hard to wrap your mind around relativity, not because it is mathematically challenging but because it is philosophically challenging. And the reason it is challenging is because, as Wolfson says, we don't have enough first-hand experience with things moving fast relative to ourselves.

8.2.6 Time Dilation

Okay, fasten your seat belts, here we go! This section finally marks the beginning of relativity – the consequences of taking the speed of light to be constant in all uniformly moving reference frames. The first consequence presented by Wolfson is the easiest to present, but it is still conceptually difficult. All of the arguments and presentations of the previous sections and chapters lead one to accept what is presented in this section as "true." But it is certainly not "obvious." So take the time to read this section carefully, and read it more than once. Make sure you understand what Wolfson is emphasizing. Hopefully, the example of the light bouncing back and forth between mirrors is convincing. But remember that it is time that is the issue, not something about light and mirrors. Different observers must experience time differently if they measure the speed of light to be the same. It just has to be that way if the speed of light is constant.

8.2.7 "Moving Clocks Run Slow"

This is another great section. It again emphasizes the right things, from the distinction about "moving clocks" in the first paragraph to the synchronization and difference between "seeing" and "observing" at the end of the section. The discussion of clocks in the middle (with C, C_1, and C_2)

may be a bit difficult to follow, but it is worth it, and it will be very useful in the next few chapters. Go over this section until you have it!

8.2.8   Getting Quantitative

Take this section slowly and work through the numerical examples for yourself. You'll see that it isn't that hard. And you'll see that the key to "significant" relativistic effects is "significant" speed of one reference frame relative to another.

8.2.9   Wrapping It Up

So, if we accept that the laws of physics are the same for all observers whose motion is uniform, we are forced to accept that those observers will measure different values for the time between two events. The difference in the measurements of time are only significant if the relative speed of the observers is large. So who cares? Well, the practical answer is that you only have to worry about relativity for objects that are moving fast relative to you. The philosophical answer is that relativity shows us that our everyday notion of time is simply wrong. Time is relative!

8.3   After you read

1. What is the difference between an event and a place? between an event and a time?

2. What is wrong with summarizing time dilation as "moving clocks run slow"?

3. Come up with a good, concise sentence (or two) which summarizes the concept of time dilation.

4. Observer A throws a ball straight up in the air and then catches it when it comes straight back down. Observer B is flying by in a high-speed craft and is able to see the whole thing. Both A and B use identical, very precise stopwatches to measure the time between the release of the ball and when it is caught. If B observes that the ball is in the air for exactly 1.0000... seconds, will A measure a time less than, equal to, or greater than 1.0000... seconds?

5. If, in the previous situation, B is moving past A at a speed equal to half the speed of light, what would one predict for A's measurement of the time that the ball is in the air? What if B's speed relative to A was $0.8c$?

6. Now switch it around: A is still the one throwing the ball straight up, but it is A that measures the time the ball is in the air and finds that it is exactly 1.0000... seconds. If B is moving at $0.5c$ past A, what does B measure as the time the ball is in the air? What if B is moving at $0.99c$?

9 Star Trips and Squeezed Space

9.1 Before you read

The previous chapter finally introduced one of the consequences of accepting that the speed of light is the same in all uniformly moving reference frames – time dilation. This chapter continues the discussion of that concept and transitions to another consequence – length contraction. In addition, this chapter explains one of the experiments which provides evidence that these strange consequences are, in fact, real, and it discusses a fairly famous conundrum of relativity – the so-called Twin Paradox.

To get the most out of this chapter, it really helps to be really comfortable solving distance, time, and speed problems. For example, how long does it take to drive from Seattle to Olympia (about 70 miles) if you can maintain an average speed of 70 miles per hour? What if you can only average 50 miles an hour? How fast do you have to go to get from Seattle to Olympia in 45 minutes? If you go 70 miles an hour for an hour and a half, how far will you have gone?

You should be able to make up lots of similar questions and solve them all backwards and forwards. Try it!

9.2 As you read

9.2.1 Years and Light-Years

In class, we are going to go one step further than Wolfson does here. The idea that he presents of measuring space in units of light-years is good. But we can actually just drop the 'light' and measure space in years or any other unit of time. We can do that because we now have an absolute conversion factor – the speed of light. And it is useful to do because it makes the mathematics much more simple. Wolfson will actually take this extra step in chapter 13, but we don't need to wait. Practice measuring space in units of time (seconds, minutes, days, years, and more). And then turn it around and measure time in units of space (meters, kilometers, and even feet or yards if you want).

9.2.2 Star Trip! One-Way

Hopefully, after the last chapter, this section is a pretty easy read. Wolfson lays out the thought experiment nicely. And, as usual, he will be using this same situation again in future chapters, so make sure that you follow what he has set up and that you understand not only what results he is emphasizing but how he got those results and why they deserve to be emphasized.

9.2.3   Squeezing Space

At first, this section may seem to be both too simple and too odd. Again, you need to suspend your disbelief for a bit to get through what Wolfson is trying to present. He is using a very simple example to show one of the other major consequences of relativity – length contraction. When you think about length contraction and time dilation separately, they will eventually make sense. When you try to think about both of them at the same time, it may make your head hurt. But you can eventually open your mind enough to allow both concepts to be in there, together, quite harmoniously. What has to be taken out of your mind are your common-sense notions of space and time. They are not absolute. Both space and time are relative. You and someone moving relative to you will disagree about measurements of the space and the time separating two events.

9.2.4   It Really Happens!

We will use quite a bit of class time to go over the experiment discussed in this section. It is a wonderful experiment, and the evidence it provides in support of the predictions of relativity is quite convincing. Make sure that, between the class time and the presentation in this section, you understand how the experiment was set up, what the predicted results would have been prior to relativity, and what relativity predicted.

9.2.5   A Round-Trip Star Trip – The Twins Paradox

You may have heard of the Twins Paradox. The first thing you should know, as a result of this class, is that it is not a paradox at all! There are real paradoxes out there, but this is not one of them. Secondly, you should be able to explain what the supposed paradox is; it is not just the fact that one twin ends up younger than the other. And finally, you should be able to explain your way out of the supposed paradox by citing the proper rules of special relativity. Think you can do all that? This section does it all.

9.2.6   Time Travel!

Can you travel to the past? We don't really know. Can you travel to the future? Sure! You're doing it all the time! Can you travel to the future faster than someone else? That is the interesting question from the perspective of relativity. The answer, as we can see from the supposed Twin Paradox, is yes! When you move relative to someone else, you travel into his or her future faster than he or she does.

9.3   After you read

1. In the Sun's reference frame, Earth and Sun are approximately 8 minutes apart. Use the fact that the speed of light is 300 000 km/s to figure out how many kilometers there are between Earth and Sun (on average).

2. In the Earth's reference frame, Moon is approximately 3.844×10^5 km from Earth. How would you express this distance in units of time? What does that expression tell you about what (or when) we see as we look at the Moon?

3. A spaceship zooms past Earth and then passes the Sun. If the spaceship is moving at a constant speed of $0.5c$ relative to the Sun, how many minutes would elapse between passing Earth and passing Sun? (You should feel compelled to give two answers to this question.)

4. In the situation of the previous question, what would the person in the spaceship calculate as the number of kilometers between Earth and Sun? How does that relate to the figure you calculated in question 1?

5. How is the half-life of a radioactive element like a clock? If half-lives are a measure of time, are they also a measure of space? In other words, can you measure half-lives in meters?

6. Would it be appropriate to claim that the half-life of an element is relative? In other words, does the half-life of an element depend on the speed of the element relative to the observer?

7. If the Mount Washington experiment were repeated, but the detector was set to detect muons moving at $0.5c$ rather than $0.995c$, would the detector find a greater difference or less of a difference between the mountain-top observations and the sea-level observations? *Hint:* Would the mountain seem taller or shorter to the slower muons?

8. Why is it not possible for the age difference between the twins to be greater than 40 years if the trip in the Twin Paradox is to a star 20 light-years away?

10   The Same Time?

10.1   Before you read

Have you read chapter 13? If not, skip to chapter 13 and come back when you're done!

This chapter introduces the last big consequence of relativity – the relativity of simultaneity. Before you start to read this chapter, think about what it means for two events to be simultaneous. How do you determine if two things that happen in different locations occur at the same time? What kind of corrections do you have to make for the time it takes for the information about the events to get to you?

10.2   As you read

10.2.1   A Test of Faith

This section contains one of the keys to my own understanding of just how deep relativity goes. It is simple enough to accept that when you look at the clocks in a spaceship zooming by, you observe that they "run slow." The obvious flip side is that the person in the spaceship looking at your clocks would argue that your clocks "run fast." But this is not what relativity predicts. Relativity predicts that the person in the spaceship observes that your clocks "run slow." This is not just some arbitrary difference of opinion that can be fixed by convention. It is deeper than that. Either you and the person in the spaceship are both right, or you are both wrong. But either way, you cannot work it out by just looking at each other's clocks. You have to look at your relative speed as well!

If you have read chapter 13, you know that you and the person in the spaceship will agree on something – the spacetime interval. The two of you can use the spacetime interval to verify that each other's clocks are indeed working properly.

10.2.2   Simultaneity Is Relative!

Wolfson goes to a lot of trouble to set up the thought experiment in this section. As you should know by now, he has good reasons for doing so. So take the time to make sure you know what "event A" and "event B" are and how they appear in the different reference frames. Go slowly enough to be sure of both the what and the why involved with the example. You may want to draw your own diagrams or even draw planes on two cards and move the cards past each other. Do whatever it takes to completely visualize the situation.

10.2.3 "Moving Clocks Run Slow" Revisited

While this section is very well laid out, it may still be confusing. In class, we will use the spacetime interval to solve the contradiction of you and the person in the spaceship *each* claiming that the other's clocks "run slow." Wolfson uses simultaneity arguments to get out of the contradiction. Either way, you should come away with the sense both that relativity implies some very weird things about time, space, and simultaneity and that the weirdnesses *do not* involve any contradictions. As Wolfson says at the end of this section, there are lots of claims about contradictions and paradoxes involving relativity, but there is always a way out. Relativity does work. According to all the evidence, it appears to be true. It's just not obvious.

The real value in reading and understanding this section is to get a deeper understanding of how to work with issues of simultaneity and the synchronization of clocks. But if it just isn't sinking in, it is okay to leave this section without fully understanding it.

10.3 After you read

1. A spaceship zooms by Earth at a relative speed of $0.8c$, and the person inside holds a meterstick up so that it is pointed in the direction of the ships motion as observed by you, standing on Earth. You also hold a meterstick up, aligned parallel to the meterstick in the spaceship. How long does the meterstick in the spaceship appear to be according to you? How long does your meterstick appear to be according to the person in the spaceship?

2. Can you explain your way out of the apparent contradiction involved in the observations of the previous question? *Hint:* You should be able to do it with the spacetime interval if you can define the situation in terms of events. You may also be able to use some simultaneity arguments similar to Wolfson's example of the airplanes flying toward each other. Either way, this is a challenge. Don't get too frustrated. Discuss it with others and see how far you can get.

11   Past, Present, Future, and... Elsewhere

11.1   Before you read

You've done it! You have covered the major consequences of relativity! All that's left is to tie up a few loose ends. One issue is the order of events. It can be worrisome to find that not only is simultaneity relative, but the order of events can be reversed to some observers in some situations. This chapter presents a good summary of these issues and a way to understand them.

But this is all really icing on the cake. The concepts in this chapter are not as central as those in the previous chapters. They are still slightly conceptually challenging, but overall this should be an easy read.

11.2   As you read

Notice again how careful Wolfson is with the words he uses. And again, he uses a great thought experiment with the Mars Rover. And this one is real, at least in the sense that the scientists working with the Rover had to plan for the time delay involved in sending signals to the Rover.

Work through the spacetime diagram carefully, and make sure you know what each region means and what defines the boundary of each region.

11.3   After you read

1. Come up with some examples of events that are in your past, your future, and your elsewhere. For the past a future, come up with events that are on your worldline and events that are not.

2. One of the great things about cartoons is their ability to ignore the laws of physics. Can you think of any examples of sequences of events in cartoons where something from an event's elsewhere was portrayed as a cause of the event? Why is this more "acceptable," even in cartoons, than something from an event's future being portrayed as a cause of the event?

12   Faster than Light?

12.1   Before you read

This chapter is just tying up a few more loose ends. It is even less central than the previous chapter. However, it does have a wonderful formula which can be used to show that

$$300000 \text{ km/s} + 300000 \text{ km/s} = 300000 \text{ km/s}.$$

Or more precisely, it shows that $c + c = c$. It's true! It's just not obvious!

12.2   As you read

While the first half of this chapter is approachable within the context of this class, the last half is beyond what we will be covering. So read it all, but don't worry if there are parts you don't understand. The key idea for our purposes is just the velocity addition formula.

12.3   After you read

1. Work through the velocity addition formula for the case where both u and v are 0.75.

2. Work through the velocity addition formula for the case where both u and v are 1.0. Do you see why this shows that $c + c = c$ and thus that

$$300000 \text{ km/s} + 300000 \text{ km/s} = 300000 \text{ km/s ?}$$

13   Is Everything Relative?

13.1   Before you read

This chapter really fits quite nicely between chapters 9 and 10. Wolfson delays it because it is more mathematical than he wants to be in his presentation of the basic ideas of relativity. But the spacetime interval introduced in this chapter is actually a great starting point for working out the consequences of relativity. As Wolfson mentions, Taylor and Wheeler start their book with it, and I encourage anyone who is really interested in relativity to go get *Spacetime Physics* and work through it. It is great! It is a much higher level text, but it is the source of much of what we use in class to supplement Wolfson's presentation.

13.2   As you read

We will be going over the information in this chapter in detail in class. Get as much as you can out of the reading, but expect to go even further in class.

13.3   After you read

1. Take the time to define concisely what it means to say that measurements of quantity are "relative." How is this different from saying that the measurements of a quantity are "arbitrary"?

2. How do people solve issues of "arbitrariness" in measurements? How do people solve issues of "relativity" in measurements?

3. Make a list of quantities that are relative and a list of quantities that are not.

4. What might it mean to say that certain "qualities" are relative (or not) rather than "quantities"?