Reading Physics

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A Guide to Understanding Classical Mechanics without Mathematical Expressions

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To Hye Sun, Arin and Joowon

Abstract

This book was written to help college students understand physics without complicated math. Each year, thousands of college students pursuing business and humanities degrees find themselves taking a course in introductory physics. But many will have serious trouble solving physics problems because they don't have enough experience using mathematical equations. Understanding physics is challenging without a strong math background but not impossible. Unlike other introductions to physics, this book explains the basic concepts in classical mechanics with a minimal number of mathematical expressions, so new students can spend their time learning physics, not math. The result is not only a better understanding of physics but possibly a better grade. This study guide covers the three aspects of classical mechanics: basics of motion, rules for gravitational interaction among two or more objects, and rotational motion. The bottom line is that this book was written to help students better understand the mathematical parts of undergraduate classical mechanics so that they can concentrate on learning physics, not math.

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Prologue

"It was almost 50 percent."

Yes, it was almost always about 50 percent. What was that about? I had been teaching general physics courses, and it was the average percentage of students having trouble understanding basic mathematics. Even considering that most students in the course pursued their academic interests in business and humanities, seeing that percentage was an alarm to me. I thought about it hard. What was going on? Was there something I could do to at least mitigate the issue? In the end, having such thoughts led me to do something to help them understand the classical mechanics better. So, I began writing my "we read physics" series.

I have no doubt that mathematics is a useful and highly effective tool to play with when studying physics. To some extent, it is necessary to grasp basic mathematical concepts for those who consider majoring in physics or other engineering sciences. But you know what? In the end, those who major in physics need to utilize it over and over, so mathematics is going to be a part of their life. They will get it eventually.

But what about students not majoring in physics or other engineering science? What about students preparing for medical school or other professional school exams without having that sort of scientific background? Are they going to have sufficient time to grasp the mathematics part of the classical mechanics? How about motivating the students not majoring in physics and encouraging them to go over the materials being covered in undergraduate classical mechanics if they don't have enough time to fully understand them?

My experiences taught me a lesson: the reality is brutal. It really is. Most students do not even have opportunities to read and focus on the physics parts in general physics. They just do not have that time. So, what do they do instead? Yes, they spend their time on understanding the mathematical side of the physics instead. What is the consequence? Well, they end up working on their assignments using the mathematical equations without understanding why they do so much and do it that way. Then, when they are asked to work on some projectile motion, they get lost and things get worse and worse by the time they meet Newton's laws.

Coming back to the percentage, almost 50 percent of students in my classes had that issue. Yes, it was about 50 percent of them. The bottom line is that I could not simply ignore the issue but needed to take some action instead and deal with it and try to come up with a resolution, a practical resolution that we can all consider for students studying physics in the future.

Let us think about time for a moment. When is the best time to initiate the rescue? After having their first test in class, it might be too late for instructors to initiate their motivation back again. For many students, they simply follow what is being covered in class and get lost further. Then, even before they realize it, the semester is over. That is the end of the story.

This causes a few issues. First, students might think physics is just about using equations and solving problems, even without understanding the equations. I am not saying that is not important, but if that is all they study and get lost, we need to think about our traditional approaches. Furthermore, all they are going to remember is the mathematical part of physics, not the physics part of it. Combining these two issues, students end up having no fun taking their first physics course. In particular, the latter can cause more serious issues for those studying and preparing for an admission test. The test is mainly about reading a paragraph on physics topics and working on their problems. It is not only about playing with numbers but also about understanding the materials instead. So, those who spent too much time focusing on the mathematical parts of classical mechanics are going to have hard time grasping the core concepts of the questions in the exams. What can we do to resolve these issues?

Reading Physics is written to help them out, particularly those who struggle with understanding the fundamentals of vectors and trigonometric functions and for those eagerly looking for a way to understand the physics part of physics in classical mechanics better. Some may say it is not practical or possible to do so. However, I truly believe that reading this book before or while taking a course in physics is going to help students get motivated to study further and get them prepared to understand the physics side of physics. In terms of practicality, that is better than just getting lost in the middle and not studying physics anymore. It is better than not studying at all. We, as a physics community, need to be more realistic in our approach toward educating students.

One more thing: the author tried to minimize introducing numerical equations in this book. Almost everything is written in plain sentences. Why is that? It gives you an opportunity to read it through and then read it again without getting interrupted by the mathematics when you are having trouble understanding them. Think of how many times students ended up getting lost in understanding a single equation and then ended up closing their book and never looking back. It happens more than you think. I did my best to avoid that tragedy.

Does that mean that reading this book is going to be sufficient for students to gain an overall knowledge of classical mechanics and that this is going to be an ultimate resource for them preparing for their medical school admission test? Probably not. I would say that this is written as a starting point for your studying physics. After reading this book, my recommendation is to study further by reading books with many mathematical expressions. I strongly encourage you to study the mathematical portion of the classical mechanics using other books or notes. You can go over some video lectures on your own, for instance. When you do so, you will have a much less hard time if you read this book first, understand the fundamentals, and then study or take lectures in classical mechanics.

In summary, I truly hope that this book helps students who are having trouble to understand the mathematical parts in undergraduate classical mechanics. I do strongly hope that this book is going to function as a bridge through which students, who are having issues understanding classical mechanics, are going to better understand the physics side of it. It will be even better if students get inspired to study physics further and think like physicists. Thank you, and welcome to the world of classical mechanics.

CHAPTER 1

Kinematics

We study mechanical motion associated with a single object in a system using some physical quantities.

Day 1
Everything is relative

Jae: I drove my car 100 miles per hour yesterday.
Adam: Well, that could be dangerous.
Chris: Wait a second, *with respect to what* did you drive your car at that speed?

What a lovely day. It was lovely to go outside. After this chain of thoughts, I decided to go on a trip to New York. I live in Columbia, the capital of South Carolina, so I decided to drive on a highway to get to Charlotte, a city in North Carolina, and then take a plane to get to New York from there. To tell you the truth, there was a physics conference that I wanted badly to attend, so I needed to get there anyway.

But you know what? I was so excited that I drove too fast. I drove 100 miles per hour on the highway. And, to make the case more interesting, everyone thought that it was such a lovely day and that led to a police officer driving a car at the same speed on the opposite side. In other words, a police car was driving 100 miles per hour on the opposite side. Question: what was the speed of the police car? Was it 100 miles per hour? Or 200 miles per hour? Or some other speed?

Now we are getting to the real story. If you decided to go with the first choice as your answer, that is great, although we may just need one little piece of information to fully describe the motion in a more practical manner. In any case, you can start reading this book in a joyful manner.

On the other hand, if you went with the second choice as your answer, that is awesome. Why? Because you might have been thinking about the "relativeness" associated with physical quantities such as velocity. Hint: think about the title of this lesson. In any case, you are also ready to have some joyful time studying classical mechanics. It is waiting for you!

Or, if you decided to go with the last choice, the "some other speed," something that you come up with on your own, that is truly and really awesome. Why? Because making that choice tells me that you do understand the fundamentals of relativeness. Or, as a best-case scenario, you can come up with an answer on your own. Just in case, if your answer happened to be something like, “It depends on how we set a reference,” then, well, you really got me there. I can tell you that you may jump on to the next lesson and read the rest of the book thoroughly with joy and cheers. Why? Because coming up with such an answer tells me that you already understand important aspects of the fundamentals of the relativeness associated with physical quantities. Believe it or not, all the lessons in this book heavily rely on your understanding of “relativeness.” Everything is relative. You will see the importance of understanding the point over and over when you end up studying Newton’s laws in dynamics. Figure 1.1 illustrates this point. In essence, you are a being in motion, but depending on how it is being measured, the degree of your being in motion is going to be recorded differently.

Coming back to the main subject, here is the bottom line: we should have a reference with which a physical quantity can be measured or calculated. In addition, the numerical value associated with a measured quantity “depends on” where we set the reference. There are no exceptions. It may sound simple, but it is important to grasp the main point here, so I encourage you to digest the essence of the relativeness before moving on to the next lesson. Again, we need to have a reference to quantify physical quantities. Depending on where the reference point is, the size of the measured physical quantity could be different. For instance, coming back to the case of driving a car on a highway, if there happened to be someone standing still on the road measuring the speed of the police car, then the person is going to think the speed of the police car is 100 miles per hour. However, if you drive your car 100 miles per hour and measure the speed, you are going to think the police car is approaching you going 200 miles per hour. If it is hard to imagine the point here, think about your experiences of driving a car on a highway. Do the cars on the other side of the highway seem to be moving faster than the cars that are on the same side of road? Figure 1.2 might help you understand the point better.

You drive your car 100 miles per hour with respect to someone standing still. At the same time, when a police car is driving the same speed as you, coming from the opposite direction, you might think that the police car is approaching you at 200 miles per hour. The speed depends on how and where we set a reference.

Well, it sounds very odd, doesn't it? You may think that a mechanical motion can be quantified with an absolute value. Well, not in reality. That is what makes studying physics and engineering science so interesting. As you read this book and go over some practice questions, you are going to understand the fundamentals of the relativeness more clearly.

The next lesson is going to be about vectors in physics. If you do not fully understand the relativeness clearly at this moment, that is okay. Let us move on for now, and you can come back to this lesson once you go over the kinematics part first. It will help you understand the essence of relativeness more clearly and provide you with an opportunity to think about references in physics.

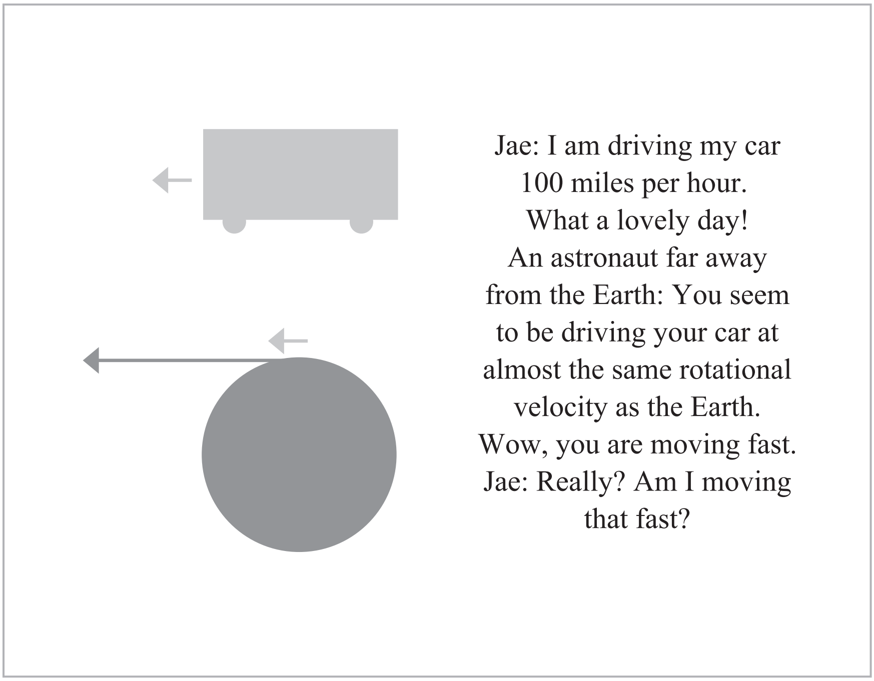

Figure 1.1: As the name of the lesson suggests, everything is relative in physics. You think that you are driving your car 100 miles per hour. Strictly speaking, when we say something like that, we do need to specify a reference. The 100 miles per hour as the velocity is probably measured with respect to the surface of the Earth. Question: what if the speed is measured by someone living far away from Earth? How is the person going to think about the velocity of you driving the car? Answer: The speed is going to be measured with a different number. Physical quantities such as speed and velocity depend on where and how we set a reference. Think about the size of the arrow in light gray on the top and the bottom part of the figure. Why are they drawn like that?

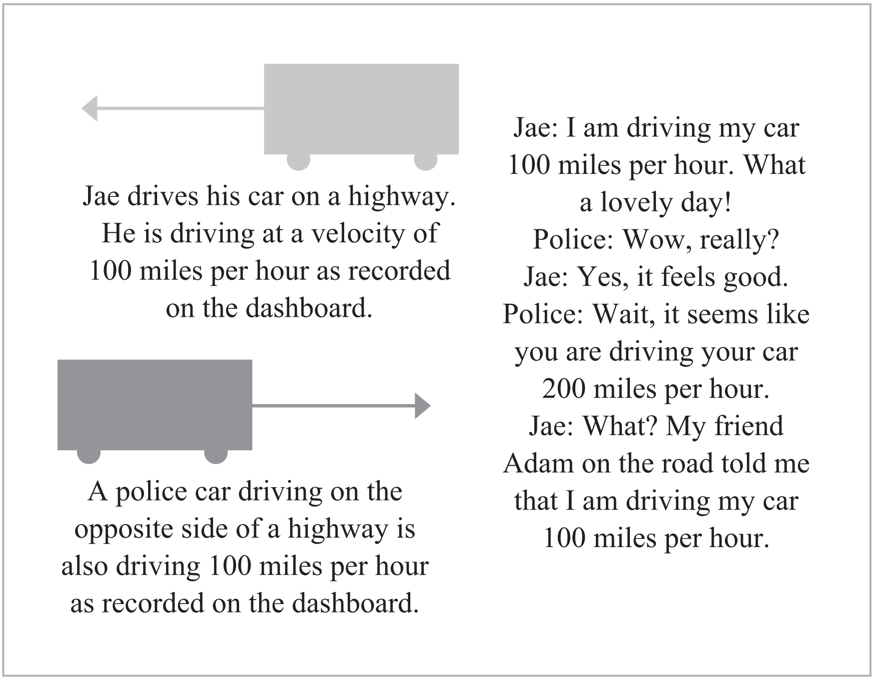

Figure 1.2: This further illustrates the relativeness of physical quantities and emphasizes the importance of specifying a reference when measuring quantities to describe motions. With respect to someone standing still on the road, Jae drives his car 100 miles per hour. However, with respect to a police car driving on the opposite side of the lane but at the same speed, the police officer is going to think you are driving 200 miles per hour. The speed that we measure depends on where and how we set a reference. It always does.

Remember that grasping the essence of the lesson may not appear to be important when studying classical mechanics. It may appear to be so since we assume the surface of the Earth to be our reference when working on many practice questions in kinematics, but it may not be the case when working on dynamics, where a reference can be set differently and a final quantity may be different depending on the reference. If you do not clearly understand this lesson, you can go ahead and study the kinematics part, but I strongly encourage you to come back to this lesson one more time, read it through, and ensure that you understand this lesson before going on to study dynamics. You will have a much easier time when taking an introduction to classical mechanics later.

Problems:

Describe whether you can measure a physical quantity without a reference point. If you can, why is that? If you can't, why not?

You drive a car 100 miles per hour on a highway with respect to someone standing still on the side of the highway and a policeman drives his or her car on the opposite side of the lane with a hundred-mile-per-hour velocity. Calculate the size of the velocity of the police car with respect to "your car."

You drive a car at a hundred miles per hour on a highway with respect to someone standing still on the side of the highway and a policeman drives his or her car on the opposite side of the lane with a 100-mile-per-hour velocity. It is a rainy day, and the raindrops move down vertically at 100 miles per hour. Calculate the velocity of the raindrop with respect to your car. Is the velocity going to be same when measured by someone standing still on the side of a highway?

Day 2
Vector

> "Vector is a quantity with a magnitude and a direction, and scalar is a quantity with a magnitude only. In general, a mechanical motion can be represented by a vector. It needs to be a vector, not a scalar."

Back in December 2009, I had a trip to New York, one of the major cities in the United States. I went there to attend a meeting, and I enjoyed the nice weather. While staying there, I realized that New York is such an interesting city and different from where I had been living for many years. In any case, I learned a lot of physics while attending the meeting, but, interestingly, I learned a lot more about teaching physics when returning to my hometown. Here comes the story.

I had to take three flights back to Columbia, my hometown city in the state of South Carolina; the first flight was from New York to Charlotte, the second one from Charlotte to Atlanta, and the last one from Atlanta to Columbia. There was no issue with the first flight going from New York to Charlotte. I enjoyed the flight. But, as you may know, things happen. While waiting in an airport in Charlotte, I was told that they were having a small issue with the fuel tank in the plane. The tank was leaking. In the end, fixing the leak was taking too long, so the agents began to offer lodgings to the customers. I was one of them. After waiting for about 10 minutes or so, I spoke with one of the customer service agents. The agent looked through my flight itinerary and started to say something, "Why are you not going to …?"

The agent did not finish the sentence, but it did not take much time for me to guess what they wanted to say. With all probability, the agent wanted to say the following: "Why are you not driving directly from here to your hometown?" Let us think about that. Why was the agent about to say something like that to me?

Just driving from the city of Charlotte to the city of Columbia, it would only take about 90 minutes, but taking two more flights, it would take a lot more than 1 hour and 30 minutes. The flight from Charlotte to Atlanta would take about 2 hours. There would be waiting time at the Atlanta airport, and then the flight from Atlanta to Columbia alone would take about 1 hour or so. Therefore, it would take at least 10 hours of my time to get to Columbia. The customer agent immediately noticed that fact when going over my itinerary. Figure 2.1 might help you understand the situation better; in terms of the starting and the ending position, driving down to Columbia or taking two flights would realize the same goal. At the same moment, I realized that this would be a good example to explain to the students in my class.

Let us go back to the issue again and think about some relevant information to my going from Charlotte to Columbia as going over Figure 2.1. What would be my travel distance if I chose to drive from Charlotte to Columbia? Say it would be about 100 miles. Now, what happens if I choose to take the two flights? The distance from Charlotte to Atlanta is going to be about 400 miles and from Atlanta to Columbia is 300 miles; so, the total distance would be about 700 miles. What a huge difference.

In the end, either way, the fact of the matter was that I would be moving from Charlotte to Columbia, but I needed to travel 100 miles in the first situation and 700 miles in the second one. Again, either way, my departing place and destination would be the same, but the total travel distance is different by about 600 miles, depending on which route I take. What is going on?

Here comes the important lesson: direction matters when going from Charlotte to Columbia or from one place to another in general, and depending on which direction I chose to go, the total distance could be different. There are an infinite number of possibilities that we can think of as far as choosing a route goes. That means that when describing motion associated with an object, we need to choose a single route, and both direction and magnitude need to be specified.

Question: how do we do that? We introduce a "vector," an important mathematical quantity that we use a lot when studying physics.

When describing the motion of an object, both magnitude and direction matters, so we need to introduce a vector, a quantity that carries information regarding both a magnitude and a direction.

In mathematical terms, you can think of a vector as,

$$\text{Vector} = \{\text{Magnitude, Direction}\}$$

Going back to the story, in the former case, if I took the shortest route, going directly from Charlotte to Columbia, it would get me to my hometown in the shortest time and that could certainly be represented as a vector. The magnitude is going to be the distance between the two cities, and the direction is going to be the direction that goes directly down from Charlotte to Columbia.

Now, let us go over Figure 2.1 one more time. It is going to be simply drawing an arrow as a straight line, where the tail is at Charlotte and the head is at Columbia, and where the length of the vector represents the distance between the two cities. What is important to remember is that we always need both the size and the directional information to represent the shortest route between two cities. If the destination is not Columbia, but say, Chicago, then a different vector is needed because the direction of moving from Charlotte to Chicago is going to be different from my moving from Charlotte to Columbia. Furthermore, the moving distance is going to be different too.

You may ask the following question: what if I chose to head to Atlanta first and then from Atlanta to Columbia instead? Then the direction of my moving from Charlotte to Atlanta would not be aligned with that of moving directly from Charlotte to Columbia, so in the end I would need to take another flight. I needed to take two flights, each of which take me from one place to another, but, in the end, taking the two flights together gets me to my destination. So, here we learned another important lesson: the motions can be represented by vectors. On top of that, we can also add them or subtract one from the other.

My going from Charlotte to Atlanta can be represented as a vector, the distance as the length of the vector, and the direction representing the arrow of the vector. We can do the same for my going from Atlanta to Columbia. Now, let us think for a moment. Taking both "vectors" together, as mentioned before, I ended up arriving in my hometown, which is the same as going directly from Charlotte to Columbia.

Again, that is all that matters when describing a motion. So, the two vectors can be added and can be represented as the vector of directly going from Charlotte to Columbia. Summarizing it,

> We can add vectors: a vector representing going from Charlotte to Atlanta and another vector representing going from Atlanta to Columbia, and the added vectors can be represented by a single vector that represents my going directly from Charlotte to Columbia. We can do the same when subtracting vectors too. You just flip it.

Just out of curiosity, let us think about going from Columbia to Charlotte. Can that be represented as a vector? Yes, it certainly can because it can be represented as a mechanical motion. It can be represented by a vector of going from Charlotte to Columbia but with a small difference, and that is "the head of the arrow" being in Charlotte, not in Columbia. What does that mean? Answer: That means that we just flip the vector to the opposite direction so that the head of the vector as an arrow represents the destination, and the tail represents the departing place. That is represented as a vector that represents going from Charlotte to Columbia; mathematically, you simply add a negative symbol in front.

So far, I described a few properties of a vector using my going from Charlotte to Columbia by two different routes. Again, a vector has both a magnitude and a direction. Vectors can be added, and vectors with a minus symbol represent a quantity that has the same magnitude but an opposite direction. There are more intriguing and interesting properties associated with vectors, but let us move on. You may find additional properties in other literature if you are interested. I think I have said enough about the importance of understanding vectors when studying classical mechanics. Let us move on to the next subject.