Motion in a Straight Line: Crash Course Physics #1

Crash Course: Physics
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Hi. I'm Dr. Shini Somara and I hear you want to learn physics. I have to say, good choice.

Physics is the science of how the world, really the whole universe, works. And I don't know if you've noticed, but in the world I live in, things tend to move around, a lot. So that's what we're going to study first, the science of motion. And it turns out to be incredibly useful, for figuring out things like where you are, where you've been or how you're moving through the world.

Why is that worth knowing? Well, for one thing, the police use physics to decide exactly how fast you're moving through the world and if that motion happens to break the law. So if you're gonna understand how and why you got that ticket they gave you that ticket they gave you and maybe even know enough to dispute it, you have to know the science of motion too.

And in order to do that, you'll need to understand a few essential conditions that describe your physical place in the universe. Conditions like time, position, velocity, and acceleration.

So to talk about all of these things at the same time you'll need a set of equations that links all of them together. These are called the kinematic equations. So for the next few minutes, let's talk about how you can figure out your place in the world, literally, which just might help you beat that speeding ticket.

Let's say you're driving on a straight stretch of highway. Say, someplace nice and flat, on the wide open spaces of the Northern Plains of the United States. Say... North Dakota. You come across a red light and even though there are no cars in sight, you stop; because you're a good driver who obeys traffic laws. Then the light turns green and you hit the gas and exactly seven seconds later, you hear the sirens and see the flashing lights of a police car. You're promptly served with a ticket for speeding in a hundred kilometer an hour zone.

But wait! Were you really going that fast? Did you actually break the law? You can't really tell because the speedometer in your car is broken. So you need to find another way to figure out how fast you were going and decide if you want to take this up with Johnny Law in court.

That's where physics comes in, the physics of moving in a straight line. Let's start by talking about how your car was moving. Driving along a straight highway is an example of one-dimensional motion because the car can only move back and forth along that line. That's the difference from something that's free to move in all three dimensions, like a boomerang flying through the air. And instead of describing that motion just in terms of speed, or direction, like a police officer or other non-physicist might do, we physicists describe it with math. Maths that measure the four main conditions of the car's movement, it's time, position, velocity, and acceleration.

Time simply tells you how long you were driving for.

Position is also important, it lets you know where you are and where you were. It can even be negative. For one-dimensional motion, there are only two directions you can move in. In this case, forward or backward, east or west.

So, if the change in position, known as displacement, is positive, you'll know you've moved in one of those directions. If it's negative, you're traveling the other way. But which direction is positive and which is negative? That's totally arbitrary. You could decide that east should be positive and west negative, or the other way around, but the answers you get will mean the same thing. You just have to make sure to keep track of which direction is positive, and keep that in mind when you're talking about velocity and acceleration too.

Velocity is the way your position changes over time, and it's also a pretty big deal. It's kind of like speed, but just like with displacement, it also tells you which direction you're moving in, based on whether it's positive or negative.

Now what about when your velocity changes? That's the fourth quality of movement you'll want to pay attention to, acceleration. If you've ever been in a car when someone slammed on the gas, that feeling of being pressed back against your seat is acceleration, your velocity is changing.

So how do we plot out all of these different conditions that describe the movement of you and your vehicle through the plains of North Dakota? A non-physicist might visualize this movement on something like a map, but for us, graphs are the most useful way to show how all this change in position is happening.

Graphs are generally presented as position versus time, with position on the vertical axis and time on the horizontal axis. We'll label your position as x and time as t.

Now let's imagine three different scenarios for how you drove through this small town and graph each one.

First, let's say that after you went through the red light, you just stayed in one spot. Say, at four meters from the light, for three seconds. From that moment, the graph of your position would just be a flat line at x equals four meters, like this.

Now, what if you didn't stop but instead were coasting at one meter per second? Then the line would be diagonal to show how your position was changing, like this.

And the third time, let's say you were standing still at first at the four meter mark, but then you hit the gas, and you moved in such a way that after one second you went one meter in the positive direction and after two seconds you went four meters and after three seconds you've gone nine meters. In that case, you end up with a graph that's all curvy, like this.

But there's more going on in these scenarios than just your position and time. You also have to be able to graph your velocity and acceleration. So to graphy your velocity, you'd put your velocity on the vertical axis and time on the horizontal axis. And you'll note since velocity is measured as the change in position over time, it's measured in meters per second.

The graph for acceleration is quite similar. Acceleration, a, goes on the vertical and time goes on the horizontal. And since acceleration is measured as the change in meters per second, its units are meters per second per second, otherwise known as meters per second squared.

So time, position, velocity, and acceleration all relate to each other. Velocity is the change in position over time and acceleration is the change in velocity over time. And often your velocity will be different from moment to moment, like the third time you drove down the highway, when you hit the gas.

But let's say you wanted to know your average velocity for a certain period, say for those first three seconds. All you have to do is take the change in position and divide it by the change in time.

Figuring out how much something is changing just means that you have to subtract its starting value from its final value.

Since, as physicists, we'll end up doing that a lot, we abbreviate that difference using the lowercase Greek letter delta. So we can use that to write the equation for average velocity. It's just delta x over

delta t; the change in position over the change in time.

Now what about the third scenario? When you had your foot on the gas and kept accelerating. You started out at the four meter mark and ended up at the thirteen meter mark. So your change in position, or delta x, would be thirteen minus four, or nine meters. You started at zero seconds and ended at three seconds, meaning that your delta t was three seconds. Over three seconds you moved nine meters. That's three meters per second.

The equation we use to describe average acceleration is a lot like the one for average velocity because it's just the change in velocity divided by the change in time. So in that case, your equation would be delta v over delta t. And... here's something that is incredibly handy. Since we're talking about constant acceleration, that is acceleration that takes place at a constant rate, we can rearrange this equation to get v equals v times zero plus a t. That's average velocity equaling to velocity at time zero plus the product of acceleration times time. This, my fellow physicist, is an equation we'll be using a lot.

We call it the definition of acceleration because that's exactly what it is. It's saying that constant acceleration is equal to the change in velocity divided by the change in time. We just use algebra to move the variables around.

Now, it's worth noting that there are lots of different kinds of acceleration, ones that don't involve speeding tickets, like when something's falling. The force of gravity pulling it down is making it accelerate at 9.81 meters per second squared which physicists often abbreviate as a lowercase g. So we'll just call that constant small g... There's a capital g that's going to come up later.

So the definition of acceleration is the first of the two main kinematic equations that we'll be using. But it only links velocity, acceleration and time. What about position?

There's an equation for that too, the second kinematic equation which we'll call the displacement curve because it takes your acceleration, your starting velocity and how long you were moving for, and uses that information to figure out what your displacement was. And your displacement curve equation looks like this. It makes sense, if you think about it. If your acceleration is the change in your velocity and your velocity is the change in your position, then there should be some way to link all of them together.

Now there are lots of other kinematic equations too, like these. But you only really need to know the first two, the definition of acceleration and the displacement curve. The others are just different ways of rearranging these main two. And because these two equations have so many terms in common you can use them together really easily. For example, if you know your acceleration and your starting and final velocities to figure out how much time you were traveling for. Then you could plug that value into the displacement curve equation and use it to find your displacement.

Now we know what the kinematic equations are, we can finally use the power of physics to find out whether you were speeding when the cops pulled you over. As with most physics problems, the first thing we need to do is write down everything we know.

In this case we know your initial velocity, v nought, was zero, and your time, t, was seven seconds. The first thing we need to find is your acceleration, which we can get using the displacement curve. Plugging in everything we know, we find that your acceleration, a, was five meters per second squared. Then we can plug all of that into the definition of acceleration to find your final velocity, like this. We learn that you were going 35 meters per second when the cops pulled you over. That's 126 kilometers an hour. So you definitely deserve that ticket. Sorry.

But in this very first episode of Crash Course Physics you learned all about position, velocity, and acceleration. We also talked about the two main kinematic equations: the definition of acceleration and the displacement curve.

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