Introduction to Physics

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1 Course Outline

This course covers the essentials of algebra-based mechanics. The purpose of this course is to provide you, the reader, with an understanding of the physical world around you.

There are four major sections of this course:

1. Unit 1: Determinism
2. Unit 2: Conservation Principles
3. Unit 3: Thermal Physics
4. Unit 3: Wave Motion

2 Unit 1: Determinism

2.1 Overview

I first want to provide an overview of Determinism to give you a birds-eye view of the processes we will employ to solve physics problems. This section is not meant to be dissected in detail so I would avoid getting caught up in minutiae.

Determinism is a philosophy of science that centers on the relationship between cause and effect. Determinism was formulated by Sir Isaac Newton and was a radical departure from existing scientific philosophy. Determinism begins with the premise that bodies are under the influence with certain interactions with their surroundings that push and pull on the body. These interactions, which we call *forces* in physics, impact the motion of the bodies in some way. The key point of Determinism is that, if given enough information about these forces acting on a body, one could calculate the resulting motion of the body to any desired precision. For example, if we were to drop an egg on the floor, we could (in principle) calculate where every speck of egg ends up on the floor if (and this is a big *if*) we could calculate all of the forces acting on every speck of egg during the event.

Determinism therefore physically relates cause and effect. With Determinism, everything we see around us happens for a reason: All we have to do is find the underlying causes. From this philosophy grew modern science such as psychology (that is, people didn't do crazy things because they were driven by spirits; rather, there must be physical reasons for their behavior) and biology (plants grew not because of God's will, but because there were forces at work making the plant larger). At that point, scientists began to investigate these causes, from which sprang modern experimental methods.

Consider some physical process that has taken place (or is about to take place). For example, suppose a cannonball is shot out of a cannon, or a car comes to a screeching halt, or a bridge collapses. Determinism involves the study of the causes of these events and the resulting effects. For example, when gunpowder is exploded, the expanding gases force the cannonball out of the cannon and into the air. Gravity also acts on the cannonball as it sails through the air. The effect is that (1) the cannonball travels in an arc and lands on the ground some distance away from the cannon and (2) the cannonball hits the ground at a certain speed and traveling in a certain direction.

A car coming to a screeching halt is also an example of cause and effect. Friction from the road (a force) *causes* the car to slow down. The *effect* is, while friction acts on the car (1) its speed drops down to 0 and (2) it travels a certain distance (called the braking distance).

From this point on, we will call these causes *forces*. The effects will be described by physical properties called *displacement* and *velocity*. (We will define these terms more precisely later in this unit). Therefore, so far:

- causes $\longleftrightarrow$ forces acting on the object
- effects $\longleftrightarrow$ displacement and velocity of the object

In this course, we will examine physical events by

- *analyzing* the causes and from them *predicting* the effects (a process called *deduction*) or
- *measuring* the effects and from them *inferring* the causes (a process called *induction*).

To understand the difference between the two processes, consider an airplane flying at altitude that suddenly loses one of its wings. According to Determinism, if we know all there is to know about the forces acting on the plane after it loses its wing and while it is impacting on the ground, then we would be able to calculate to absolute certainty the location of every airplane part on the ground.

We can turn this example around by looking at the wreckage pattern and inferring what caused it. We would measure where every speck of wreckage was located and then use that information to infer what we think caused the crash. However, we can never know for sure what caused the air crash because there are an infinite number of ways a set of causes can combine to produce this particular wreckage pattern.

Therefore, the first process in the itemized list above (the deductive process) is much stronger than the second (the inductive process). The reason is simple: Given a set of causes, Determinism mandates there can be only one effect. However, given a certain effect, there can be any number of potential causes.

2.2 Enter acceleration

We can summarize these two approaches to solving physics problems with the following diagram:

$$\text{analyze causes} \Longrightarrow \text{predict effect (deduction)} \tag{1}$$

$$\text{infer causes} \Longleftarrow \text{measure effects (induction)} \tag{2}$$

But how do we do this? That is, if we understand the causes, how do we predict the effects? And if we have measured the effects, how do we infer the causes? The answers to both questions is contained in a physical property called *acceleration*, which we will denote as $\vec{a}$. In other words, if we know the causes of an event, we can compute the acceleration and, once found, use this acceleration to predict the effects. By the same token, if we measure the effects of an event, we can compute the acceleration and use this acceleration to infer the causes. In both cases, finding this property called acceleration is of paramount importance. Therefore we can add a bit more detail to our preceding diagrams:

$$\text{analyze causes} \Longrightarrow \text{ acceleration } (\vec{\mathbf{a}}) \Longrightarrow \text{predict effect} \tag{3}$$

$$\text{infer causes} \Longleftarrow \text{ acceleration } (\vec{\mathbf{a}}) \Longleftarrow \text{measure effects} \tag{4}$$

(We will describe this magical property called acceleration in more detail later.)

To find this acceleration we need mathematical tools. There are two types of tools at our disposal:

- Newton's Second Law, $\vec{a} = \Sigma\vec{F}/m$, where $\Sigma\vec{F}$ is the combination of all forces acting on the body and m is the mass of the body.
- Equations of Motion, $\vec{v}_{\mathrm{f}} = \vec{v}_{\mathrm{o}} + \vec{a}t$ and $\vec{d} = \vec{v}_{\mathrm{o}}t + (1/2)\vec{a}t^2$, where $\vec{v}_{\mathrm{o}}$ is the initial velocity of the body, $\vec{v}_{\mathrm{f}}$ is the final velocity of the body, $\vec{d}$ is the displacement the body travels during the event, and t is the time in which the process evolves.

So, we can once again update our diagram:

$$\text{Newton}'\text{s Second Law} \Longrightarrow \text{ acceleration } (\vec{a}) \Longrightarrow \text{Equations of Motion} \tag{5}$$

$$\text{Newton}'\text{s Second Law} \Longleftarrow \text{ acceleration } \vec{a} \Longleftarrow \text{Equations of Motion} \tag{6}$$

2.3 Examples

By now, your head may be spinning. There is a lot of philosophy in the preceding section along with new vocabulary and even a few equations. So let us apply the preceding diagrams to a simple system to illustrate the process. We will find that all problems over the next few weeks can be solved using the same approach as found in the following examples.

We also have this mysterious variable called mass (m). We will describe what this means later. For now, just consider it a physical property of an object. We also have noted that $\Sigma\vec{F}$ is the combination of all forces acting on the body; we will simplify this system by assuming only *one* force acts on the system.

Consider a block of wood being pushed to the right by a force equal to 10 units. (Later, we will describe these physical properties in terms of units but for now let us just treat them as numbers. Typically, force will be measured in newtons.) Suppose the mass of the block is 2 units (e.g., kilograms). Knowing this, I would like to predict how fast this force will make the block travel 3 units of time (e.g., seconds) after the force starts pushing on it.

This is a prediction problem involving deduction. We know that we need to find the acceleration of the system. We apply the tool called Newton's second law to find this acceleration:

$$\vec{a} = \Sigma\vec{F}/m \tag{7}$$

This becomes

$$\vec{a} = 10/2 = 5 \text{ units.} \tag{8}$$

So, now that we have the acceleration, we can make our prediction using one of the equations of motion tools.

$$\vec{v}_{\mathrm{f}} = \vec{v}_{\mathrm{o}} + \vec{a}t \tag{9}$$

This becomes

$$\vec{v}_\mathrm{f} = 0 + (5)(3) = 15 \text{ units} \tag{10}$$

We're finished! We took the causes (the force acting on the block), computed the acceleration, and then made a prediction that 3 seconds later the block would be moving at a speed of 15 units (e.g., meters per second or miles per hour, depending on which unit system we are using).

Let us resort to another example. In this case, I observe a block of mass 4 units and notice that it takes a distance of 16 units to increase from rest to a velocity of 2 units. The question is: What caused this behavior?

Here, we have measured the effects, but we need to find the causes. Regardless, we need to find the acceleration of the block. I look at my Equations of Motion tools and notice that one of them will work, namely:

$$\vec{d} = \vec{v}_\mathrm{o} t + (1/2)\vec{a}t^2 \tag{11}$$

Because $\vec{v}_0 = 0$ (that is, the block starts at rest, this becomes

$$16 = (0)t + (1/2)\vec{a}(2)^2 \tag{12}$$

Therefore, the acceleration must be 8 units.

We can then use this acceleration value to find the forces acting on the block using the Newton's Second Law tool:

$$\vec{a} = \Sigma\vec{F}/m \tag{13}$$

We have assumed that only force acts on the block, so $\Sigma\vec{F} = \vec{F}$. Therefore

$$8 = \vec{F}/4 \tag{14}$$

Therefore, the combination of all forces acting on the block that caused this motion must be 32 units of strength. And since we are assuming only one force is acting on the block, then this force must equal 32 units.

Every problem that you will encounter will be one of these two types, that is:

$$\text{Newton's Second Law} \Longrightarrow \text{ acceleration } (\vec{\mathbf{a}}) \Longrightarrow \text{Equations of Motion} \tag{15}$$

$$\text{Newton's Second Law} \Longleftarrow \text{ acceleration } (\vec{\mathbf{a}}) \Longleftarrow \text{Equations of Motion} \tag{16}$$

The ability to recognize this interplay between cause and effect is the key to solving deterministic problems.

2.4 Trouble in Paradise

Physics is not an easy subject and you should have an inkling by now that there must be some complicating factors. And there are two:

1. In the above, the sum of the forces acting on the block was simple because we assumed there was only one. In this course, the forces acting on a system (that is, the causes) will usually number more than one and will typically not be so obvious.

2. The arrows on top of the variables, which we have so far ignored, indicate that the direction certain properties point *matter*. And since these properties do not always point along the same direction, we need a special mathematical approach to take this into account. We call this mathematical approach *vector summation*.

We also have a few more loose ends to tie up. For one, we introduced this property called *mass* and learned that it impacts the amount of acceleration we experience when examining the causes using Newton's second law. We will need to understand this property at some point. We also used terms like displacement and velocity but did not dive deeply into their meaning. We will have to correct that deficiency as well. And last, but certainly not least, we need to develop a thorough understanding of acceleration beyond using it as the gateway between cause and effect.

Learning vector summation now will take center stage. Once learned, we will turn our approach to understanding the equations of motion and acceleration deeper. Only then will we complete the picture by examining Newton's Second Law.