CONCEPTS IN MODERN SCIENCE

for Catholic High School Students

FIRST EDITION

CHRIST THE KING BOOKS

Printed in the United States of America

First Printing, 2020

ISBN 9781637940068

Publisher:

Christ the King Books

25150 Oregon Trail Road

St Marys, KS 66536

www.ckbooks.org

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Lesson 1 A God-given desire

Think about some of the interactions you have had with the world around you. You have seen objects different in size, color, and shape. You have heard sounds loud, soft, high, low, pleasant, and unpleasant. You have smelled odors strong and weak, pleasant and unpleasant; tasted flavors sour and sweet, pleasant and unpleasant. You have felt things hot and cold, rough and smooth, as well as hard and soft.

Beyond these varied but everyday sense perceptions, you have other types of common experiences. You have gone beyond mere sense perceptions and reasoned about things around you. You have concluded, from many experiences, that some things are alive, others not. (You are quite familiar with what it is to be alive since you are alive!) You interact every day with different kinds of materials: metals, plastics, wood, glass, water, etc. Although these raw materials are not alive, there is very much that can be learned about them beyond that which is easily sensible. You have probably seen many kinds of weather: sunshine, rain, snow; very hot, mild, and freezing cold; calm, breezy, and violently windy days; beautiful sunsets as well as severe storms with lightning. You have looked into the night sky and probably have been awed by the size, distance, and mystery of the objects there.

There are other kinds of experiences you probably had which, although not as common as the above, still must have made quite an impression on you: beautiful rainbows, the wonders of magnetism, fire and its effects, boiling water and steam, static electricity, and so on. You are not alone! We have all had these common but wonderful experiences.

Different reactions amongst people to the beautiful and mysterious things in life

Even though we all have such common experiences, yet people react very differently in regard to these wonderful experiences in nature. As you read the list below, **pause and ask yourself which category you perhaps fit into:**

1) Some people, apparently too busy, hurriedly move past the marvels of nature.
2) Some people pause to enjoy the interesting and beautiful things of nature for a short time on a mere sense level ("Wow, look at those beautiful colors!" etc.), but do little thinking beyond that sense level.
3) Some people go further, engaging their minds by asking, "Why is that happening? What causes that?" Yet they do this only occasionally and are not habitualized to asking such questions.
4) Others are in the habit of being alert, stopping to ask themselves such questions about the things they see in life.
5) Others go the furthest by trying to get answers to such questions by researching, or even designing and performing their own experiments.

Aristotle

Wherever you think you fit in the above list, what matters most is that we can all improve and learn to live fuller, richer lives by striving to always be observant and to desire to learn. A man is still a man even though he may not strive to learn and be observant; but he could be much better and happier were he to develop good intellectual habits.

This is a good point in the book to discuss a great man that we will reference several times in this textbook. One of the greatest thinkers ever born was Aristotle. He was born about 384 BC in Macedonia, Greece and died in 322 BC. He was tutor to the famous general, Alexander the Great. Aristotle was a student of the famous philosopher Plato and studied at Plato's famous school called *The Academy*. As Aristotle grew to be his own thinker, however, he began to disagree deeply on many important matters with Plato – whom he otherwise profoundly respected. Eventually, Aristotle founded his own school, the famous *Lyceum* in Athens, where he also taught. His disciples were known as the Peripatetics (itinerants), due to their habit of walking about as they spoke and lectured. Aristotle was interested in almost every known field of science at the time, and his influence lasts till today. He practiced the virtue of wonder to an eminently high degree, and there was hardly a subject area he left untouched by his writings.

A bit about St. Thomas Aquinas

To appreciate the greatness of Aristotle, allow us a quick side note. The Catholic Church's greatest theologian was St. Thomas Aquinas who lived from 1225 – 1274, an era which was perhaps the height of the great Middle Ages. Although reaching an extremely high degree of sanctity, St. Thomas is perhaps better known for his immense learning and wisdom. This is so much the case that many popes have insisted that St. Thomas Aquinas' writings should be the foundation and anchor of all seminarian training, priestly studies, and the Catholic intellectual life in general.

But what does St. Thomas have to do with Aristotle? Although Aristotle was not a Catholic (as he lived over 300 years before Christ), St. Thomas eagerly read and soaked up his writings and wisdom; in fact, it is fair to say St. Thomas was in large part formed by Aristotle. Aristotle even proved the existence of God by pure reason! St. Thomas, aided by grace, a good Catholic formation, and an extremely pure mind, saw that Aristotle for the most part correctly perceived nature and the world around him, and that his writings meshed with Revelation. The key thing is that St. Thomas realized that Aristotle's wisdom is not only beautiful in itself, but it could also be used to explain Catholic theology. Thus, in his masterful theological works, St. Thomas quotes Aristotle so much that he simply refers to him as "The Philosopher". This is one of many strengths that make St. Thomas so wonderful – he beautifully applies human wisdom – especially Aristotle's – to explaining Divine Revelation. It is important to see this, however: Divine Revelation itself does not itself *depend upon* human wisdom and philosophy; rather, philosophy can serve as a tool to help make Revelation clearer to us men, whose intellects are weakened after the fall of Adam. Philosophy is thus "the handmaiden of theology", as the wise men say.

At the beginning of perhaps his greatest philosophical work called the *Metaphysics*, Aristotle stresses that **all men by nature desire to know**[1]. He goes further and says in many other places that not only do men want to know *that* something is, but they want to know *why* things are as they are – that is, men finally want to know the *causes* of things.

Aristotle is attributing to us a desire, a force, which urges us on toward knowledge. Of course, for some this desire does not exercise great influence; but for some it plays an important role in their lives. Those who fit into the categories 3, 4, or 5 listed above are more or less exercising and acting on this natural desire. That is, they are exercising the beautiful virtue of *wonder*.

Man is designed by God with a strong desire to know

But we can also ask about ourselves: *Why* is it that I want to know the causes of things? To answer this question, it helps to recall a few basic catechism questions. You know by your catechism that God made all things, including you. You also probably remember the catechism question: "*Why* did God make you?" and the answer was something like this: "God made me to **know**, love, and serve Him so that I can be happy with Him forever in heaven."[2] Notice that knowing comes first in the list. Some have argued through the centuries that man is made primarily to love, but St. Thomas Aquinas shows that loving comes *after* knowing. We can only love what we know; the loving happens naturally as a consequence of our knowing. But the knowing is where "the action" is, and where man's soul is at rest.

The catechism also tells us that God made everything else on the face of the earth for man's enjoyment. This means that animals, plants, magnets, fire, rainbows, electricity, chemicals, as well as everything else the natural sciences study, are finally made for man! How then do these catechism answers help us to know, "*Why* does man want to know"? The catechism helps us this way: because all men are made by God and for God, He has designed us simply to *want to know*. Just as we *want to eat*, *want to sing, want to love,* we also are designed to *want to know.* In fact, St. Thomas and Aristotle show that this desire to know is our very highest desire. This may not seem to be the case,

[1] "All men by nature desire to know. And indication of this is the delight we take in our senses; for even apart from their usefulness they are loved for themselves…" Aristotle, *Metaphysics*

[2] *Baltimore Catechism*

however, since many men sadly derive their pleasures from sense pleasures, honors, and riches. But our God-given desire to know wants to know the causes of rainbows, magnets, lightning, etc. But why? Why did God make man primarily to know?

Man's desire to know leads to God Himself, for all eternity!

Why would God design man to want to know? He implanted in us this desire to know the causes of these natural wonders for two reasons:

First, by wanting to know the causes of rainbows and countless other natural wonders, we will begin to "dig even deeper" into the world around us. If we are not lazy, and truly try to live well, we will (hopefully) eventually think about the deepest causes of everything. This will lead us to Him, Who is the Final Cause of everything! So, studying science with the proper motives can help us get to heaven! St. Augustine, who after St. Thomas is perhaps the second great theologian in the Church, wrote a famous passage, "Thou hast made us for thyself, O Lord, and *our heart* is *restless* until it finds its rest in thee."[3]

Second, the other reason is this. Have you ever wondered about the cause of something you saw, and later found the answer to your wonder? For example, have you stopped and wondered why ice floats in water? This makes sense when you discover that the cause is that ice is less dense than liquid water. How did you feel when you discovered the cause? That's right – it is simply enjoyable and good to know. In fact, one of the greatest pleasures a man can experience is to wonder about something, come to learn the answer, and then simply enjoy having and pondering the answer! Somehow, we feel fulfilled and satisfied. This enjoyment itself is another sign that man is made to know. In contrast, when we know that we do not know some important or deep question that arises, there is a certain frustration or sense of lack of fulfillment.

Studying science should therefore be enjoyable for its own sake, simply because we are doing what we are made to do – to know. We will do whatever we can in this book to make the pursuit of science enjoyable for you!

In summary then, studying science helps us to know God and at the same time gives us great pleasure. **Never study science by "leaving God out of the picture". This makes no sense! Remember that by studying science, you are really studying the effects (results) of God's actions. He is the Cause of all these things you study, as well as the Cause of the pleasure you experience by coming to *know*.** In fact, for pious Catholics who "do science rightly", their love of God may well increase because we see more deeply how good, almighty, and wise He is, how good He is *to us*, and how much He wants us to be with Him forever.

Do exercises for Lesson 1

[3] St. Augustine, *Confessions*

Lesson 2 Genus, Species, Specific Difference

The English word 'science' is derived from the Latin word *scientia*, which simply means 'knowledge'. In English, however, the word science is often used in a narrower sense: A **science** is an organized body of knowledge about a particular subject, beginning from well-established principles. A **principle** is a starting point, a beginning, a foundation. Principles can be things found in nature, such as blood. For example, "One principle of the human body is blood". But often principles are simply basic truths upon which we build other truths. For example, geometry is the science of magnitude (e.g. figures, lines, etc.). Some of geometry's principles are:

- well-known and obvious truths such as, "The whole is greater than the part."
- definitions such as, "A *line* is breadthless length."

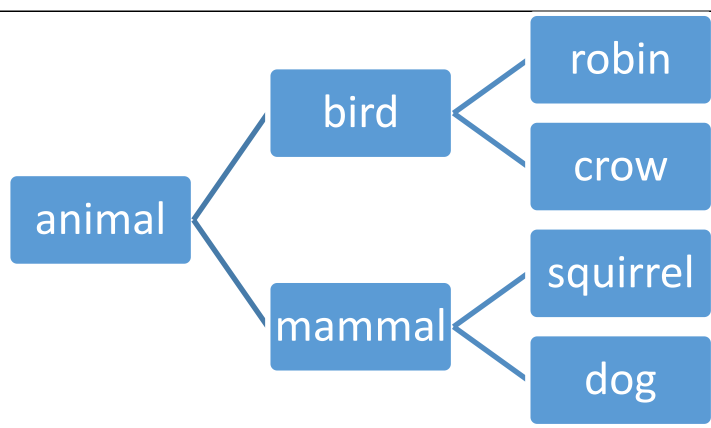
Upon basic principles such as these, the entire science of geometry can then be carefully built up into an entire organized system of conclusions. In such an organized system, in order for us to really *know* the higher and more advanced truths, we must first understand the lower and more basic truths – it is a real system of truths, each built upon the other.

In the present course you are studying, however, we will **not** be building a large, hierarchical system of truths. You will do this later in systematic science courses such as chemistry, biology, and physics, as well as mathematics courses such as geometry. Rather, in this book we will merely introduce you to a careful study of certain critical concepts which are necessary to move forward with those more advanced sciences. Before we can begin our study of these concepts, we need to learn the meanings of some critical terms used in science and logic.

Terms used in good definitions: genus, species, specific difference

In science, as with any logical investigation, we try to form good definitions. But before we can learn about making good definitions, let us investigate some terms borrowed from **logic** – the science which investigates correct thinking. The following are the terms we need to study: **genus, species,** and **specific difference.** Study carefully the two relationship diagrams below which will help you understand these terms. The first diagram is from nature, and the second from geometry. Strive to see the relationships between the items.

Genus and species



Here we see that the most general (generic) thing is animal. Everything "underneath" that is either a group of animals, or a specific animal.

Of course, for simplicity, we have divided animal into just two (of the many kinds): bird and mammal.

In this diagram, animal is what Logic calls a **genus.** A **genus** is the word which gives the "what it is" of all the things organized underneath it. Since there are two things organized directly underneath the word animal, namely bird and

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Lesson 3 Forming Good Definitions

In the previous lesson, we learned that good definitions always include the genus and the specific difference of the thing being defined. For example, "An isosceles triangle is a **triangle** with just two sides equal." Here, the genus is **triangle** and the specific difference is "just two sides equal". That specific difference sets the isosceles triangle apart from, for example, the equilateral triangle, which has all three sides equal.

What would happen if the person reading our definition did not know the meaning of the genus we provide? For example, if we tell someone "An equilateral triangle is a **triangle** with all sides equal", but the person does not even know what a triangle is, then we would first have to define *triangle* for that person before we could teach him anything. You can immediately feel such a person's confusion, if someone were to tell you, "A weefle is a blue scobner." Your mind immediately tries to analyze that (nonsense) word 'scobner', but it cannot.

Note: We warn you that this is a somewhat difficult lesson. Please take your time because the concepts are very important for a correct view of science in general.

Definitions depend upon simpler, better-known terms

The above example of someone not knowing what a triangle is might seem far-fetched. Yet, everyday life as well as science can be just like that. For example, someday you may be a parent and experience a conversation like this:

"Daddy, what is that?" "That is a watermelon, son."

"What is a watermelon, Daddy?" "A watermelon is large **fruit** with sweet red flesh, son."

"What is a fruit, Daddy?" …

You see the pattern: if the child kept "drilling down" and asking, "Okay, but what is …?" the father would eventually get to such basic words, that he could go no further. He might even be tempted to tell the boy to go ask his mother instead.

An exercise in drilling down

Let us try a simplified exercise in "drilling down" in definitions. Remember, a genus is a word which gives the "what it is" of a thing, and these are shown in bold-black. The specific differences are shown in **red**:

What is an oak? An oak is a large ***tree*** *which produces acorns. (The genus of oak is 'tree'. But what is a tree?)*

What is a tree? A tree is a large ***plant*** *with a woody stem and bark etc. etc. (genus = 'plant')*

What is a plant? A plant is a living ***body*** *which cannot sense. (genus = 'body')* Animals are alive too, but they can sense while plants cannot. You might see already how we will soon be in trouble in our drilling down– we are already forced to use such a basic word as 'body'! Let us however, fearlessly continue.

What is a body? A body is a ***thing*** *containing matter. (genus = 'thing')* Yes, not all things have matter, such as angels, God, and ideas; such things are *immaterial*. But we are panicking now: we doubt we can go any further, and say what a 'thing' is. Well, let us try anyway:

What is a thing? A thing is a ??? Yes, we have no more simple idea than 'thing'. What do you think? Can you define "thing" in simpler terms, better known to us?

Keep this point in mind: when giving a series of ordered definitions, we cannot just keep drilling down forever, to more and more basic terms; there is a limit (unless we "cheat" like the dictionaries do by substituting a different word, which really ends up flipping back to the beginning of the chain where we started).

Accidents

In the previous lesson, you learned about the terms: genus, species, and specific difference. But there are two additional terms very helpful to have in your scientific and logical toolboxes: **accident** and **property**.

Consider these two definitions:

- A pencil is a writing instrument with graphite as the writing material.
- A pencil is an **orange** writing instrument with graphite as the writing material.

Definition #2 includes something that should not really be part of the definition. Not all pencils are orange. In previous decades, pencils were indeed often orange but these days many are of other colors, or are mechanical pencils, which are almost never orange. Orange is an **accident** of a pencil. An **accident** of a thing is some aspect of its being which can be added or taken away without changing the "what it is" of the thing. For example, if somehow you changed the paint of the pencil shown here from orange to blue, would it still be a pencil? It of course would be, for a blue pencil is still a pencil. Color in fact, is almost always **accidental** in things. When an attribute of something is an accident, we can state it as an adjective and say it is 'accidental'. For example, we can say, "It is accidental to this pencil that it is orange."

But when an attribute of a thing is critical to the definition and cannot be removed or changed without changing the thing into a different *kind* of thing, we say that attribute is **essential**. For example, we cannot change "three-sided" in the idea of triangle to "four-sided"; if we did, it would no longer be a triangle. "Three-sided" is essential to the definition of a triangle. **Essential** is therefore the opposite of **accidental**.

Categories of accidents

Accidents can be of many types. Here are a few:

Quantity	"That pencil is 8 inches long."	If it were only 6 inches, it would still be a pencil.
Quality	"This pencil is orange. This pencil is sharp. This pencil is hot."	If the pencil were blue, dull, or cold, it would still be a pencil.
Position	"The pencil is on top of the bookcase."	If it were moved elsewhere, it would still be a pencil.
Relation	"This is Julie's pencil."	If Julie gave it to her friend, it would still be a pencil.

Our speech and knowledge are often limited to mere accidents!

If you ponder how many things in life the above categories include, you will realize that much of what we say about things around us are accidents! For example, above, the father was explaining what a watermelon is to his son, and said, "A watermelon is large **fruit** with sweet red flesh." The father did give the correct genus (fruit). But if we think deeply about this and pay close attention to words "large", "sweet red flesh", we will see that these are merely **accidents** of a watermelon since 'large' is a quantity / relation, and both 'sweet' and 'red' are qualities. If for some reason a watermelon in your garden turned out very small, or not very sweet, we would still call it a watermelon. In fact, if there happened to be another common fruit in nature called, for example, a 'redfruit' which was also large and had sweet red flesh, we might be in trouble distinguishing watermelons from redfruits.

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Aristotle on matter and form

Aristotle wrote a wonderful treatise called *Physics* (which can also be translated as *On Nature*). In it, he defines **natural things** as those things which can undergo motion. By 'motion' here, Aristotle does not just mean movement from place to place (as we are accustomed to use the word); rather, his meaning is much broader and includes:

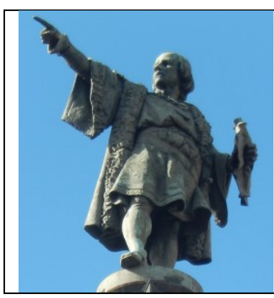
- an apple turning from red to green **(quali**tative motion)
- a body growing in size (**quant**itative motion)
- birth / death ("coming to be" / "going away" motions)

So, in short, the subject of his book *Physics* is anything that can undergo any of the above motions. But this includes all we sense around us, including ourselves! Animals, plants, rocks, stars, planets,[15] asteroids; gases, clouds; liquids, and solids: all these are natural things, since all can undergo one or more of the above types of motion.

Further, Aristotle shows that natural things have several **principles** (recall that a principle is a starting point, a beginning, a foundation). Two of those principles are **matter** and **form**. Everything found in nature has both matter and form. **Matter** then can be defined as one of several principles of nature, which when combined with form, creates natural substances. Form can be defined much the same: **Form** is one of several principles of nature, which when combined with matter, creates natural substances.

Note that one never finds just *matter* lying around in nature as some separate, colorless, formless blob. Likewise, nor does one just find a *form* just floating around, with no matter. Rather, matter and form are always found combined in nature as some **substance**. The form is what limits the matter to be a certain *kind* of substance and not some other; the matter however, individuates the thing. For example, the form "oak tree" makes this object (e.g. pointing at the the oak tree in our front yard) *a different **kind** of thing* from that object over there (e.g. pointing at my rose bush); but THIS particular matter (e.g. tapping on the actual wood of our family's oak tree) *individuates* this object from that object over there (e.g.. pointing at the oak tree in our neighbor's front yard).

We know this is hard and quite possibly confusing. A few examples might help:

	This bronze statue of the great Catholic explorer Christopher Columbus has both matter and form. Its matter is bronze (a metal made from copper and tin); its form is the beautiful shape we see. Although starting with man-made things (artifacts) such as statues is perhaps the easiest way to begin understanding the difference between matter and form, yet it is better to try to concentrate on truly natural things, such as birds, plants, rocks, etc. See the next example.	*Public Domain*

[15] Aristotle saw that the heavenly bodies such as the stars and planets did not seem to undergo change, but always appeared to stay the same in their orbits and schedules. He thus quite understandably did not consider them as natural (changeable) bodies, but as something higher. Today however our instrumentation helps us to see that they are indeed changeable things, made of chemicals just like the things around us here on Earth.

	This robin has the matter *proper to a robin*. That is, a robin cannot be formed from just any type of matter (materials like mercury, iron, or wood would not work), but only from the matter suitable for life (the complex material inside the egg). The robin's form is its soul. The "robin soul" is what forms that suitable matter into the living bird. The combination of proper matter with the "robin soul" is what makes the robin a unique **substance**. So what makes my two pet parakeets differ from one another? They both have the same form ("parakeet soul"). They even look exactly the same, and even I can hardly distinguish them. Yet, they differ because they have different matter. The matter of *this* one is not the same matter as *that* one.	*Dakota Lynch / CC BY-SA*

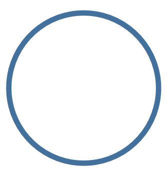
What does it mean to 'abstract'?

We can focus on just one sensation out of many happening at once

Imagine you are eating a red apple – which also happens to be crispy, juicy, and sweet. All these sensations – taste (sweetness), sight (red, round), touch (hard, wet), and hearing (crunch) combine into one experience. Yet, we can focus our attention on just one of these sensations, for example, the sensation of the sweetness. To help focus just on taste, we can close our eyes so as to not see the beautiful red, plug our ears so we do not hear the crunch, and even not touch the apple by having someone spoon feed us like an infant. By focusing on just the sweetness, we have "left the other sensations behind."

We can focus on just one idea / concept which is usually joined with others

We can do much the same in the realm of ideas. For example, consider the idea of a leather soccer ball. There are multiple ideas joined here – spherical; about eight inches wide; that classic soccer ball color pattern of alternating black and white pentagons; lightweight not heavy; made of leather – and so on. But we could focus on just one idea and separate that in our mind, even though that concept is part of the "whole soccer ball".

No abstraction	Abstracting the shape of the ball	Abstracting the material (leather)	Abstracting the geometry of the surface shapes
 *Pumbaa80 / CC BY-SA*		 *Tomascastelazo / CC BY-SA*	

To **abstract** simply means to think about one idea and not others, even though all those ideas are really part of some whole. We would not be performing abstraction however if, for example, we were to think about a tree, and then a dog, and then a triangle, etc. Rather, true abstraction is to see some whole, and then eliminate many or most aspects of that whole.

Now that you have some understanding of what it means to abstract, let us try something difficult: let us try abstracting with various materials.

We must not mix up 'matter' with 'material'

Matter is a very general term. As was said above, matter is a *principle* of all things in nature, and is always found combined with form, to make some sort of substance.

But matter is not the same idea as *material* even though we often use the words matter and material interchangeably. Materials are things such as gold, wood, air, water, flesh, tomato, and cotton. Materials are more than matter because they are composed of the principles of both matter and form. So, materials *have* matter, but they are *not* the same as matter. Thus, we can define **material** as "matter differentiated by some unique form". In order to really understand the very basic idea of matter, we have to *abstract from* whatever kind of material we see, leaving just a very general notion in our mind. Can you do it? We are going to try below.

Once again, we wish to remind you that matter is never found just "lying around" *as* mere matter. Rather, it is always found in nature combined with some form.

Even the most basic materials are composed of matter and form

You may or may not have heard of the chemical elements. **Chemical elements** are the most basic, simple substances known to man; we cannot find simpler substances existing in nature. On the following page, you will see the famous "periodic table" – the result of hundreds of years of research into materials. There is a tremendous amount of information packed into this table, although most of it you may not appreciate until you study chemistry as a subject on its own. The history of the creation this table is fascinating and ripe with opportunities for discussion. For now, however, we are just getting our feet wet by a brief exposure to it. See if you can find in the table the very lightest and simplest element known to man. (Hint: look in the upper left corner of each box for that element's "atomic weight".) The heaviest stable element (as opposed to elements which are always decomposing) is uranium. Its symbol is 'U', and it is a radioactive element used in nuclear power and nuclear weapons. Can you find it?

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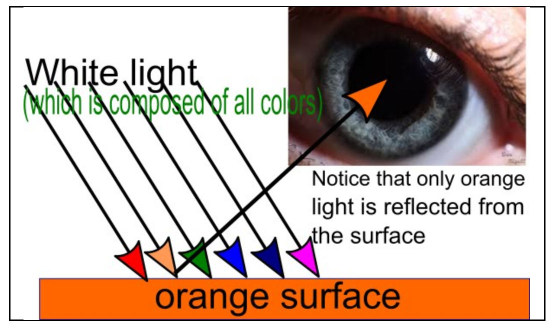
not adding anything, but merely *separating the parts of the white light*, which already contained all the colors within itself. One way Newton proved this was by taking the color band that came out of the prism, and then sending it back through another prism, which reformed it right back into a stream of pure white light. The world was astounded by the proof that white light contained all the colors within itself!

Newton, like Huygens, also wanted to know *what light is*. Based on some evidence, Newton formed a theory opposed to that of Huygens: light is a stream of tiny particles called 'corpuscles'. These tiny particles came from the sun (or whatever light source, such as a candle). Recall however, that Huygens insisted light is waves. Not surprisingly, these two great discoverers Newton and Huygens vigorously opposed one another until their deaths. This is a pity, because, as we shall see, both of them were on the right track!

Wait a minute! If white light has all the colors, why does everything not just appear bright white to us?



If Newton is correct about white light containing all visible colors in it, and if light from the sun is reflected off objects around us and comes back to our eyes, then why does not everything appear to us as a sea of blinding, pure white?

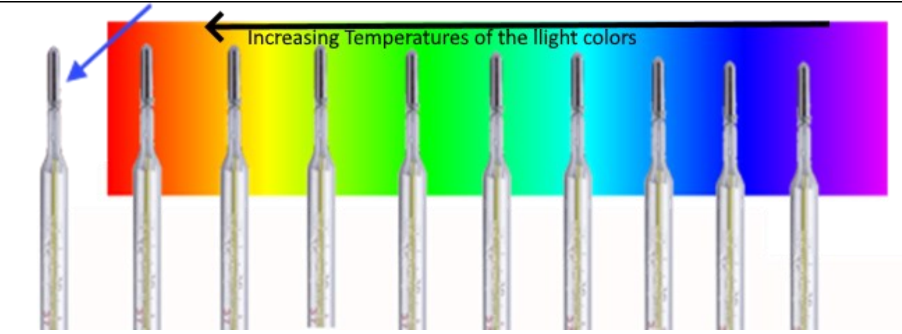
The answer is that different kinds of matter do not reflect all the various colors. Depending on the kind of matter, some will *absorb* instead of reflecting certain colors. For example, an object whose matter appears orange to us has a material makeup such that all the colors in the white light are absorbed by that surface except the orange light; the orange light then bounces off and enters our pupils. On the contrary, a black shirt absorbs almost all the visible colors; our eyes 'see' an absence of color when looking at a black object. White clothing absorbs almost no light, and all the sunlight reflects back to us – we do indeed in that case get almost all the light from the sun.

There are a few more interesting consequences of this absorption of light by objects. If light is absorbed by objects, then what do you think happens to the temperature of objects when light shines on them? Which objects' temperatures would be most affected – white or black? Do you have any experience in this area? Also, what happens to the intensity of objects' surface colors over time, when exposed to bright light? (Hint: think of something left in the sunlight for years, such as furniture near a window.) Observant men noticed such things, as we shall now see.

A tremendous discovery: energy beyond the visible light spectrum

Men saw noticed that the order of the colors in the spectrum is always the same as shown above –red as one extreme, and violet on the other end. Careful observations by other scientists who lived after Newton's time have produced very interesting finds. Sir William Herschel, another Englishman (who also discovered the planet Uranus), made two great discoveries about light and the energy spectrum surrounding it.

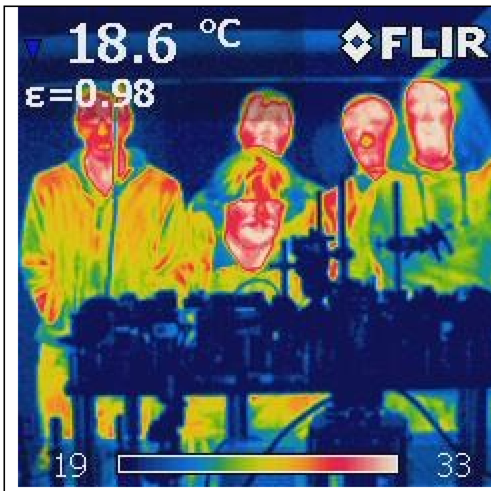
First, Herschel showed by means of many thermometers, that the *temperature* of each color band is different.



Herschel put a series of thermometers in the colors produced by the prism, including an **extra thermometer beyond the red**. To his surprise, that thermometer (marked with an arrow), placed where there is no visible light, became the warmest of them all! This discovery encouraged many other experiments by other scientists, leading to the discovery of a huge spectrum of invisible radiation as you will see below.

Even more interesting however, he noticed that, beyond the red light, there is a band of energy – invisible to us, but real – which had the highest temperature of all! This band is today called *infra-red* (the Latin preposition 'infra' means below or beyond, thus "below the red") light.

Although infrared cannot be seen by us, it is critical energy for the existence of human life. For example, about half of the energy of the sun reaches us as infrared radiation, not as visible light. When we sit near a campfire, this is mostly infrared energy reaching us. This might be surprising – you might have thought that the warmth you were feeling was air heated by the fire, and then touching your skin. (This is partly true, especially if your hand is above the fire!) But you can prove to yourself very easily that there is another source of heat reaching you that could not possibly be the air, heated by the fire. One way is to quickly open a curtain or window blind on a bright sunny day; you will instantly feel the heat on your skin. This change could not possibly be due to the air between the window and your skin being instantly heated. Of course, you might argue that most of that heat you feel is thanks to the *visible* sunlight. Thus, another and better experiment, would be something like this.



An infrared photograph of workers in a laboratory. Notice that the faces (exposed skin) show the highest amount of energy being emitted.

Tomasz Kawalec, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

At night with your parents' approval and supervision, heat a pan of water on the stove to boiling. Then, turn off the stove top and turn off the kitchen lights, and you will still feel the heat although there is no visible light coming from the pan. (If you had somehow been able to heat the pan to be glowing white hot, then you might have thought some of the heat is from visible light).

Infrared energy can be detected by special devices, even in the pitch dark. These devices show us the (invisible) infrared energy as white or red on the display, as you can see here. In fact, any object which is above 0 degrees Celsius emits infrared energy.

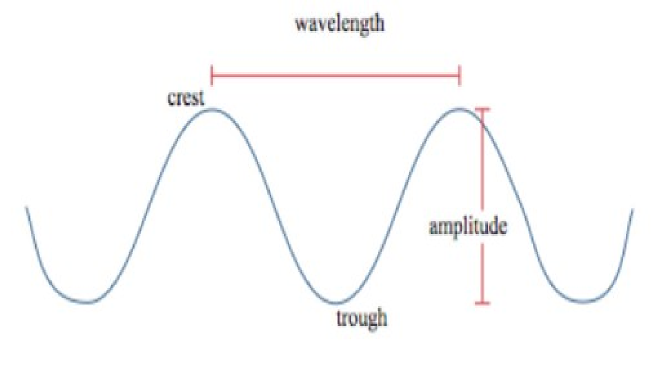
Infrared energy can also be generated by devices, such as television and other remote controls; these controls send out a thin beam of energy which is then sensed by the receiving device.

Ritter discovers ultraviolet energy

A year later, a German named Johann Ritter wondered about the opposite end of the spectrum – the violet side. Was there light beyond the violet? His experiments proved there is! He discovered *ultraviolet* (literally, "beyond the violet") light – which we now know is the invisible energy which gives us sunburn, and can cause health problems such as skin cancer. You might object that we give both infrared and ultraviolet – which are invisible to us – the title of 'light'. But it has become clear from biological experiments that certain animals other than man[18] can sense these bands. For example, infrared is sensed by snakes, fish, frogs, and others; ultraviolet by reindeer, birds, and perhaps cats and dogs. How different the world must look to brute animals than it does to us!

Color becomes measurable on a scale

Study this diagram, which simply defines and illustrates the various parts of a wave, such as the common water wave on the ocean:



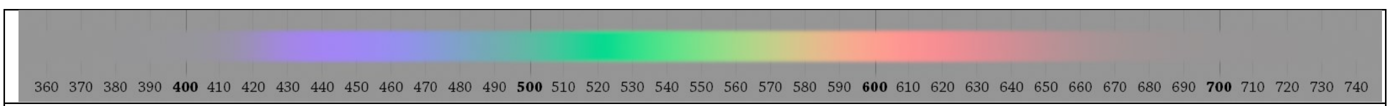
Geoff Ruth / CC BY-SA

The parts of a wave, whether it be water or light

Waves are defined as moving disturbances in the medium. But if we could freeze a wave in place for a moment, we could see that the **wavelength** is simply the distance (e.g. "3 inches") between two crests (or between two troughs). But again, the wave is in reality moving. The faster it moves along, the greater is its frequency**.** The **frequency** of a wave is therefore defined as how many complete cycles pass by a given point in one second. So if 5 waves pass by in one second, the wave has a frequency of 5 **hertz** (a hertz is a unit meaning one complete wave cycle – crest to crest – in a second).

Each of Newton and Huygens had supporters for their respective theories about light. As for those who insisted light is a wave, a way to measure and quantify the wavelengths (see definition above) was still lacking. But in 1801 the Englishman Thomas Young discovered a way to measure the wavelengths.

Young's discovery gave increasingly modern man a very technical way to define color: a **color** is visible light of a specific wavelength. Young determined that the wavelengths of the visible colors are the size of microns, or thousandths of millimeters. For example, notice in the spectrum chart below that the green light in the center of the spectrum has a wavelength of about 550 billion nanometers. This means we could give a name to that particular shade of green light. Let us, for example, call it 'lime green' and define it as "light with a wavelength of 550 billion nanometers".



The spectrum of colors with their wavelengths. The numbers represent nanometers, which is one-billionth of a meter.

Spigget / CC BY-SA

A huge series of further discoveries: Visible light is only a tiny portion of an entire spectrum of energy!

As stated above, Herschel's and Ritter's discoveries of energy / radiation beyond either side of the visible spectrum led to the discovery of many other kinds of radiation. Following them, the very observant Englishman Michael Faraday made the startling discovery that light is affected by magnetism. The great Scottish scientist James Maxwell followed up on Faraday's discoveries, put them into mathematical form, and made predictions about other kinds of waves that

[18] Man is defined, both biologically and philosophically, as an animal. St. Thomas Aquinas and great philosophers spoke as such.

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Lesson 13 Newton's Second and Third "Laws" of Motion

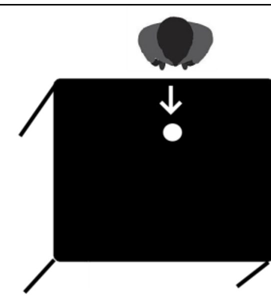
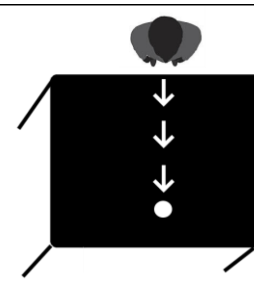
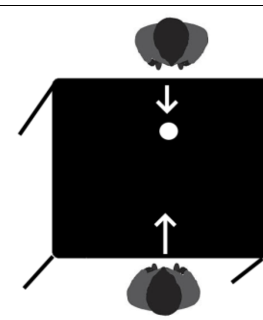
Newton's Second "Law"

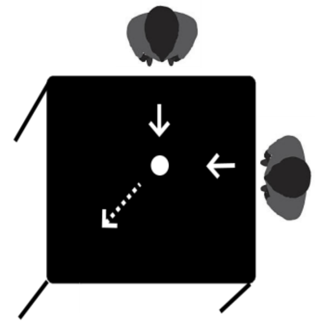
Newton's First "Law" was concerned about things *staying the same* – the fact that they will **stay** at rest or **stay** in motion. The Second "Law" is about just the opposite: how things ***will change*** if you apply new forces.

Newton's actual wording of the Second "Law" below can, at first reading, be very frightening. But have no worries! As you will see, what he is saying is not hard to understand. To give you some immediate help, we explain and illustrate his wording. Here is the short version of the Second "Law":

> The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.

In the table below, we give the full version of Newton's own words in the left column, and our comments in the middle column. In the right column is a top view of a table and a person to illustrate the idea.

"The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right [straight] **line in which that force is impressed. If a force generates a motion, a double force will generate double the motion, a triple force triple the motion …**	An object's motion will alter (speed up or slow down) in direct proportion to the amount of force applied. For example, the harder you throw a ball, the faster it goes. Or, imagine you have a lightweight plastic ball on the table in front of you. The harder you blow on it, the faster it will go.	
whether that force be impressed altogether and at once, or gradually and successively. And this motion (being always directed the same way with the generating force), if the body moved before, is added to …	It does not matter if you apply all the force at once, or in many little bursts. If you blow on the ball with one strong push, it will attain a certain velocity. But you could do the same with many little breaths, one very quickly after the other.	
or subtracted from the former motion, according as they directly conspire with or are directly contrary to each other;	Or the reverse: if you push directly against an object moving toward you, the more it slows down. For example, if a friend joins you and sits at the opposite side of the table, and blows on the ball in the opposite direction (that is, back towards you), why then, of course, the ball will slow down according to how hard your friend blows.	

or obliquely joined, when they are oblique, so as to produce a new motion compounded [joined together] **from the determination of both."**	Forced applied obliquely will result in a new motion, a motion with a different direction and speed (different velocity). Don't let Newton's wording scare you. "Oblique" simply means "slanting" or diagonal, as opposed to directly or straight at. Now imagine your friend sitting not opposite from you, but sideways from you. If you start the ball rolling by blowing on it, and your friend then blows on the ball sideways, the ball will not only move faster but will take a new diagonal direction. There are all sorts of possible variations in the direction, depending on how hard each of you blows, or where exactly you sit.	

Now, let's go on to understand each of these parts more in depth.

Understanding the proportion

Let's look a little more at Newton's explanation of the definition, particularly this part:

> **"The alteration of motion is ever proportional to the motive force impressed…If a force generates a motion, a double force will generate double the motion, a triple force triple the motion".**

A golf swing shown in five frames

HaraldMM / CC BY-SA

A good example in which we can explain this concept is with the sport of golf. Take a look at the diagram on the right. If we consider the full swing of this golfer, we can suppose that there is a particular force that he is imparting onto the ball. The ball then will accelerate and reach some velocity and will then fall and lose velocity due to gravity and air resistance. Suppose, though, that this golfer started his swing by lifting up his club only halfway up, as he is shown in the second frame. Let us assume that this generates exactly half of the force as the first swing. This swing will then generate half of the "motion", or half of the acceleration of the golf ball. This will then generate a lesser maximum velocity and a new position in which it will land. We can write these two scenarios as a proportion, like this:

$$Swing\ with\ full\ force : Swing\ with\ half\ force :: full\ velocity\ of\ golf\ ball : half\ velocity\ of\ golf\ ball$$

Or, again, using the short notation:

$$Force\ of\ Swing \propto Velocity\ Generated$$

But your friend throws in a complication…

Let us suppose you are explaining to your friend what we have just learned. You tell him, "If I throw a football and it goes 20 feet, well then, if I make a throw twice as hard, it should go 40 feet. See! There is a proportion there." But your friend is a joker who loves to argue, and says, "I'll prove you wrong." You snap back, "I bet you can't!" So you throw a football and sure enough, the throw goes 20 feet. You are just about to grab the ball a second time to throw it twice as hard and prove it will go 40 feet, but before you can, your friend substitutes a bowling ball for the football.

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