# A Theory of Mass

When I was an undergraduate philosophy major at the University of Maryland, I learned the phrase "What is mind, no matter; what is matter, never mind." At that time, I took this to be a light-hearted way to point to the duality of mind and body. I later learned that this statement was originally made by George Berkeley, an 18th century philosopher who argued for idealism. According to Berkeley, the physical world only exists in the mind of God and in the minds of people.

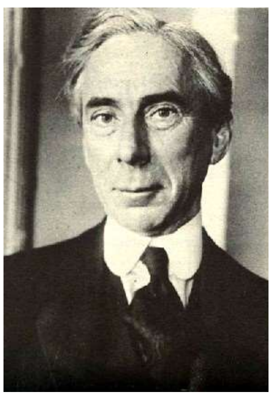


*Figure 3-1*
*Bertrand Russell*

The British philosopher Bertrand Russell told the Atlantic magazine an amusing story about this saying. When Russell became interested in philosophy, members of his family would say to him that all of philosophy can be summed up in the above saying. He recounted that he ceased being amused by the saying after hearing it 60 times, and he was relieved that when he went to Oxford, he found people who didn't think that studying philosophy was absurd.

Now, as I research flowmeters, I'm finding that understanding "what is matter" – or more precisely, "what is mass" – does matter. I also see how philosophy sheds light on matter as a physical substance. So first, before I delve into mass at the atomic level, I invite you to journey into the realm of Russell and other philosophers who explored the nature of matter and beyond.

## Idealism and Materialism

Bertrand Russell, along with G. E. Moore, is widely regarded as one of the founders of analytical philosophy, the predominant method of philosophy taught and practiced in the 20th century in

America and Britain, and also so far in the 21st century. Russell's contributions extend beyond philosophy to logic and mathematics as well.

George Berkeley was a contemporary of René Descartes, who is often called the father of modern philosophy. Descartes lived from 1596 to 1650. The span of his life overlapped with that of some other great philosophers of that time, including Thomas Hobbes and John Locke. Besides philosophy, Descartes also made major contributions to both physics and geometry. His name still lives in the Cartesian coordinate system.

While Descartes is known for saying "I think, therefore I am" (Cogito ergo sum), he defined the framework of the discussion in philosophy of mind and materialism with his definitions of mind and body. According to Descartes, body is an "extended thing," while mind or consciousness is an "unextended, immaterial thing." This raises the question of how mind/body interaction can occur. How can an extended thing such as a physical body interact with an unextended, immaterial mind?

Descartes' definitions of mind and body framed the philosophical debate on mind and body for several centuries. One of the arguments Berkeley used for his idealism is that those who believe in the existence of physical things could not show how these objects could interact with a spiritual being. While it is easy to set aside Berkeley's ideas that everything that exists including the physical world only exists in the mind of God or the minds of people as being preposterous, the alternative views are not that much more plausible. Thomas Hobbes followed the Greek philosopher Democritus and argued for materialism. This is the view that everything that exists can be accounted for in terms of material or physical principles. While this view seems more plausible than Berkeley's idealism, it requires accounting for consciousness and perception in purely physical terms.

## Descartes Has Given Us a Flawed Framework

*Figure 3-2*
*Renee Descartes*

As stated above, Descartes' framing of the mind/body problem in terms of the relation between "extended things" (body) and unextended things (mind) set the framework for the subsequent debate on this issue for centuries to come. George Berkeley was an idealist (all is mind), while Thomas Hobbes was a materialist (all is body). Spinoza believed that mind and body are two aspects of an underlying substance. In the $20^{th}$ and $21^{st}$ centuries, the power of Descartes' framework still exists, although much of the discussion has turned to the relation between mind and brain. For many materialistic and even dualistic philosophers, the term "body" in Descartes' framework has come to mean "brain." Some philosophers attempt to show the identity of mind and brain, or attempt to show that mental phenomena and perception are reducible to brain functions. More recently, philosophers such as Daniel Dennett and David Lewis have taken up this position.

## Anomalous Monism

Someone who is inclined to reject both the "all is mind" idealism and the "all is body" materialism is still left with accounting for the interaction of mind and body. In a 1970 paper called "Mental Events," Davidson proposed a theory called "anomalous monism." It is important to understand that Davidson substitutes "physical events" for talk of body, and "mental events" for talk of mind. He defines "physical events" as ones that have a physical description. He defines "mental events" as ones that have a mental description. According to this view, mind and body are not discrete substances, yet mental events such as thoughts are not reducible to physical events, or to events in the brain (neural events). This view has its roots in Spinoza. Spinoza was reacting to the difficulty in accounting for mind/body interaction, using Descartes' seemingly irreconcilable definitions of mind and body. According to Spinoza, mind and body are not separate substances, but instead are two different attributes of a single underlying substance.

Davidson formulates his anomalous monism as follows:

> "Anomalous monism resembles materialism in its claim that all events are physical, but rejects the thesis, usually considered essential to materialism, that mental phenomena can be given purely physical explanations. Anomalous monism shows an ontological bias only in that it allows the possibility that not all events are mental, while insisting that all events are physical."

Davidson has described his position as a combination of conceptual dualism and ontological monism. It is conceptual dualism in that he does not believe that mental descriptions can be reduced to physical description, or vice versa. It is ontologically monistic in that he believes that mental events are identical to physical events. This form of monism is materialism: he believes that, ontologically speaking, mental and physical events are physical events, even if they have mental descriptions.

A part of his defense of anomalous monism reads as follows:

1. For every scientific law L there exists a set of concepts and descriptions which forms a closed, homonomic domain whose elements are drawn on by L.

According to Davidson, every scientific law is governed by a closed set of concepts and descriptions that are drawn on by the law. By "a closed set of concepts" he seems to mean an interrelated set of concepts and definitions that all draw on a single field of study or body of knowledge. For example, physical laws all draw on terms and concepts defined within physics, while chemical laws similarly draw on terms and concepts defined within chemistry. Presumably, Davidson would say that the laws of physics and chemistry do not draw on mental terms and concepts. This is the import of the term "closed." It does not allow for the use of terms outside of physical and chemistry in stating the laws of physics and chemistry.

While Donald Davidson's anomalous monism represents an important advance over Spinoza's theory, his discussion suffers from the assumption made by so many philosophers after Descartes: that it is possible to divide the world into two distinct realms: the physical (material) world and the mental world. It is only when we reject this dualistic framework made most prevalent by Descartes that we can begin to understand our world.

### Why Descartes' Dualistic Framework Matters for the Concept of Mass

This book is about mass flow measurement. We are approaching this topic by first looking at the concept of mass, then looking at "mass flow," then looking at "mass flow measurement." According to the Cambridge English dictionary, the term "mass" means "the amount of matter in any solid object or in any liquid or gas." What is most important in this definition is that mass is "the amount of matter in any solid object." The definition of "matter" in the same dictionary is "physical substance in the universe."

Putting the above definitions together, we can define mass as "the amount of physical substance in a body or in any liquid or gas." What is most important in this definition is the use of the term 'physical.' When Descartes defined body as "an extended thing," he was referring to the idea that a body occupies space; it is three-dimensional. Today we would say that it has length, width, and height. Of course, mass does not account for the entire realm of the physical. According to Einstein's special theory of relativity:

$$E = mc^2$$

In this famous equation:

$E$ = energy

$m$ = mass

$c$ = the speed of light

According to this equation, mass and energy are equivalent and can be converted into each other.

### Does "Physical" Have a Single Uniform Meaning?"

In Donald Davidson's anomalous monism, he seems to be thinking of what is "physical" as meaning "what can be described in the language of chemistry and physics." However, many discussions of mind and body today focus on the relation between mental events or entities, such as thoughts, and neural events or entities that occur in the brain. While they may both be physical in some sense, talk of rocks and star explosions that may occur in physics are very different from the language of neurology. In neurology, we use terms like ‘synapse ,’ ‘cerebral cortex,’ and ‘central nervous system.’ And if we bring chemistry into the picture, matter is viewed in terms of atoms and molecules. It seems unlikely that we can use the concepts or the laws of physics and chemistry to account for what occurs in the brain, whether or not that is related in some way to what happens in the mind.

There is a similar issue with respect to biology, sociology, psychology, economics, and other sciences. Biology is the study of living things. The concepts and laws of biology deal with evolution, genetics, cells, the development of living organisms, and many other matters unrelated to chemistry and physics. Likewise, sociology deals with the behavior of people in groups. It is the study of the development, structure, and functioning of human society. Each of these sciences has its own conceptual framework and laws, and it is hard to see how they could be accounted for in terms of the language of chemistry and physics.

The point of these examples is to show that dividing the world into mental and physical objects or things, or into extended and unextended things, as Descartes did, does not begin to account for the complexity of our own world, or of the universe as a whole. In fact, trying to define a “physical object” in purely physical terms can be challenging in itself. For example, a cup is a usually round container, often with a handle, that is intended to be used for drinking. A notebook is also a physical object. However, it is a stack of pages, usually ruled and generally bound, that is used for notetaking, journaling, writing, sketching, and other ways to record thoughts and ideas. Like a cup, it is a physical object, but it is defined according to its intended purpose. And even though cups and notebooks are physical objects, they are defined according to their mental purpose.

A true account of the world, science, and our language involves a pluralistic approach that goes beyond the definitions of mind and body. Biology, sociology, and economics are all attempts to explain different aspects of the world that are different from what mind and body. They all involve terms, definitions, and laws that are not included in the language of physics or chemistry, or in descriptions of the mind. However, because this book is about mass and mass flow, instead of further developing this pluralistic view, I will focus on the physical aspects of the world, and on the explanation of matter as physical substance. In doing so, we will find that even the term 'physical' has multiple meanings, and that these meanings have important implications for the definition of mass.

## Three Conceptions of What is Physical

Even though Davidson's anomalous monism may not completely resolve the question about the relationship between mind and body, we can use his concept of a conceptual domain in coming to a better understanding of the meaning of "physical." It will become clear that the term 'physical' has at least three different senses or meanings.

This book is about mass flow measurement. We are approaching this topic by first looking at the concept of mass, then looking at "mass flow," then looking at "mass flow measurement." For many years I have written about mass flow, volumetric flow, and mass flowmeters. Yet I have struggled to understand what mass is. I understand the word, and I know how to use it, yet I don't feel that I really understand mass or mass flow. Likewise, I have struggled to understand the theories behind

Coriolis and thermal flowmeters. This chapter attempts to understand mass by going beneath the surface of observable objects and finding the origins of mass in the incredible energy of subatomic particles moving at near-light speed. Before we do that, however, we will look at the multiple meanings of the word "physical." Once we do that, we can see how the concept of mass emerges from multiple layers of atomic and subatomic elements that, while not directly observable, are nonetheless real.

While not everyone shares my puzzlement with the concept of mass, or my interest in solving the puzzle of mass, there is a good reason why this concept is so elusive. Mass is a property that we cannot observe directly, even though we can observe its effects. Many physical properties like the color yellow, height of an object, and the hardness of a rock, we can observe directly. These properties are not hidden from us and there is no need to make an inference about them in order to understand them. Similar properties include the taste of ice cream, the feeling of a cool breeze on a hot summer night, and the presence of a tree in our line of vision.

Mass is not like this; it can't be directly experienced. Instead, mass is a scientific concept that embodies certain scientific theories. As a result, to understand mass we need to understand the scientific theories that underlie the concept of mass.

*Figure 3-3 Democritus and the Atom*

The attempt to understand the nature of the physical world and what underlies its existence began at least as early as the ancient Greeks. What is the are physical objects composed of? Can we answer this question by simply dividing an object in half and then continuing these cuts until we reach some kind of fundamental element? What we find in our experience is that when we cut something in half, and then in half again, there is a limit to how many cuts we can make. For example, if we cut a piece of cheese in half and then in half again, there is a limit to how many cuts we can make until the piece of cheese is so small that it can't be further subdivided. This may have to do with the size of our knife or the type of cheese. However, even if we switch to a different type of cheese or use a smaller and sharper knife, we will eventually reach a point where the cheese simply can't be cut any further.

It must have been this type of thinking that the ancient Greek philosopher Democritus went through when he proposed the existence of an indivisible particle called the atom. Democritus, who lived from 450 BC to 370 BC, was the first person to propose this. Democritus theorized that all matter is composed of tiny, indivisible particles called "atoms" that are constantly moving through empty space, and that the different properties of matter arise from the varying shapes and sizes of these atoms. He believed that atoms are solid, indestructible, and cannot be further divided, with their differences in shape determining the characteristics of the materials they form. The word "atom" originates from the ancient Greek word "atomos," which means "indivisible" or "uncuttable."

Democritus has captured an important intuition. In the knife and cheese example, part of the problem is simply the practical one of finding a fine enough knife to cut cheese into a very small particle. But what if we move to what is theoretically possible – is it theoretically possible to cut a piece of a physical substance (matter) indefinitely until is no longer divisible? In other words, is there a smallest indivisible particle?

If we were dealing in the world of mathematics, we might answer that a smallest particle cannot be found. Mathematicians have no qualms about imagining the existence of infinite processes. According to contemporary math, the number line is populated with infinitely many points with no area. Mathematicians talk without hesitation about the existence of infinite sets and of the ability to complete an infinite series. Even the formula for the area of a circle, $\pi \times r^2$, makes us of $\pi$, an irrational number with no repeating digits. This formula is widely used in flowmeter circles because most pipes are round and it is necessary to know the area of a pipe to accurately calculate flow in the pipe.

### John Dalton's Atomic Model

Democritus' view of the atom remained the prevalent one for almost 2,000 years. In 1803, John Dalton proposed the first scientific theory of the atom. John Dalton's atomic model was the first complete scientific theory of the atom. It stated that all matter is composed of indivisible and indestructible particles called atoms.

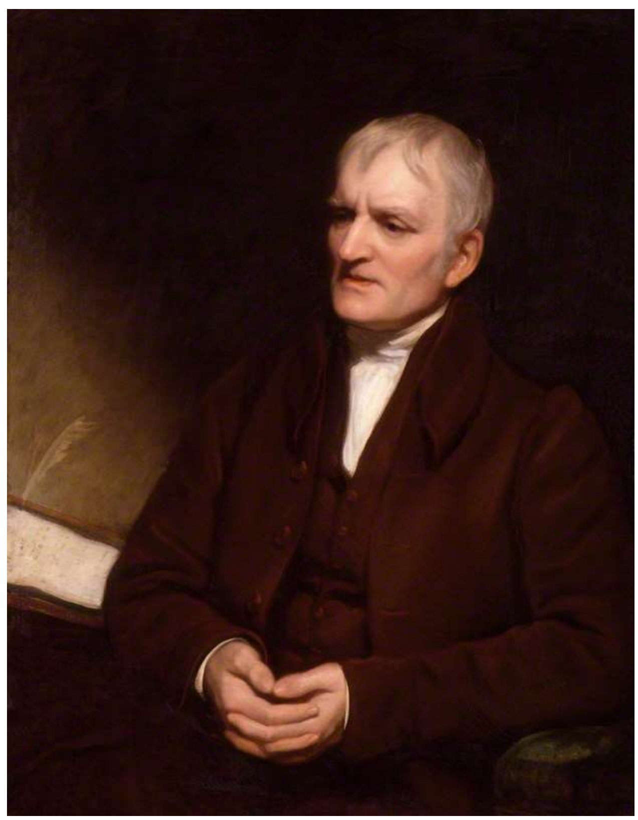


*Figure 3-4 John Dalton*

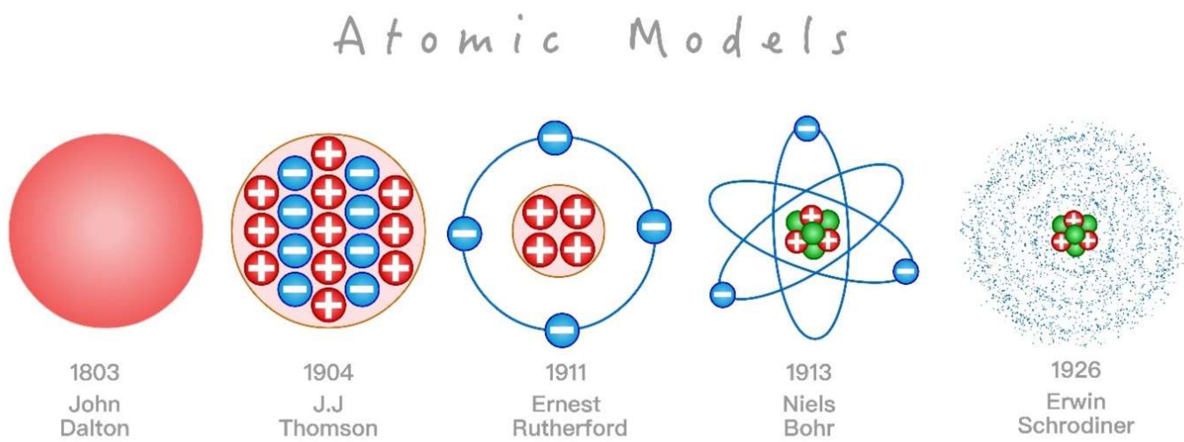



*Figure 3-5 Representations of different models of the atom*

Dalton's theory included the following key points:

- All matter is made of atoms;
- Atoms of a specific element are identical in mass and properties;
- Atoms of different elements can combine in simple whole-number ratios to form compounds;
- Chemical reactions involve the combination, rearrangement, or separation of atoms.

### J.J. Thomson's Atomic Model

The graphic above shows the development of theories of the atom, beginning with John Dalton in 1803. One hundred years later, in 1904, J.J. Thomson proposed a different atomic model. According to Thomson's model, atoms are spheres of positive charge with negatively charged electrons embedded with them, somewhat like plums in a pudding. This model followed Thomson's discovery of electrons in 1897. This discovery resulted from his experiments with cathode ray tubes.

Here are the main points of the Thomson model:

- Atoms are spheres of positive charges.
- Electrons are embedded within these spheres.
- The positive and negative charges are equal in magnitude, making atoms electrically neutral overall.

While Thomson's model lacked empirical evidence to support its claims, it did pave the way for future more accurate models of the atom.

### Ernest Rutherford's Atomic Model

The next atomic model, the Rutherford model, was proposed by Ernest Rutherford in 1911. This model describes the atom as having a small, dense, positively charged nucleus at its center, with electrons orbiting around it like planets around the sun. The Rutherford model replaced the earlier "plum pudding" model proposed by J. J. Thomson, and was a crucial step in understanding atomic structure. Here are some of the man points of the Rutherford model:

- Rutherford's experiments showed that the atom's positive charge and most of its mass are concentrated in a tiny, central region called the nucleus.
- The experiments also revealed that most of the atom is empty space.
- Electrons, with their negative charge, were proposed to orbit the nucleus in a manner somewhat like the way in which planets orbit the sun.

### Neils Bohr's Atomic Model

Two years after Rutherford's model, Neils Bohr came out with his own model. According to the Bohr model, proposed in 1913, electrons orbit the atom's nucleus in specific shells, like the way that the planets orbit the sun. Here are some main features of the Bohr model of the atom:

- Electrons move around the nucleus in circular orbits, each corresponding to a specific energy level. Electrons can only occupy certain allowed orbits, called orbital shells.
- Electrons can move between these shells by absorbing or emitting energy in the form of photons. When an electron moves to a higher level, it absorbs energy; when it moves to a lower level, it emits energy.
- The Bohr model improves on the Rutherford model by introducing the idea of specific energy levels that electrons move around in.

### Erwin Schrodinger's Atomic Model

In 1926, Erwin Schrodinger built on the work of Bohr and others, and proposed a different atomic model called the "Quantum-Wave Model." Schrödinger suggested that the movement of electrons in the atom corresponded to wave-particle duality, and consequently electrons could move around the nucleus as standing waves. Here are some of the feature of the Schrodinger model:

- It describes the movement of electrons as standing waves.

- Electrons are constantly in motion, and do not have a fixed or defined position within the atom.

- The theory does not predict the location of the electron or describe the path it takes within the atom. It only establishes a probability zone to locate the electron. These probability areas are called atomic orbitals.

- These atomic orbitals can be defined between electron clouds and have different energy levels and sub-levels.

## Current Views on Atomic Theory

Today we know that atoms are not a single, indivisible particle, as Democritus thought. Instead, they are made up of protons, neutrons, and electrons. The protons and neutrons form the nucleus of the atom, while the electrons are orbiting around the nucleus in constant motion. The term 'orbit' suggests that the electron is a solid object traveling around the nucleus, somewhat like the moon orbits the earth. However, current thinking is the electrons are more like a field of energy than a solid particle, and that they exhibit both wavelike and particle-like qualities. This is the view introduced by Schrodinger, and it is still the prevailing view today.

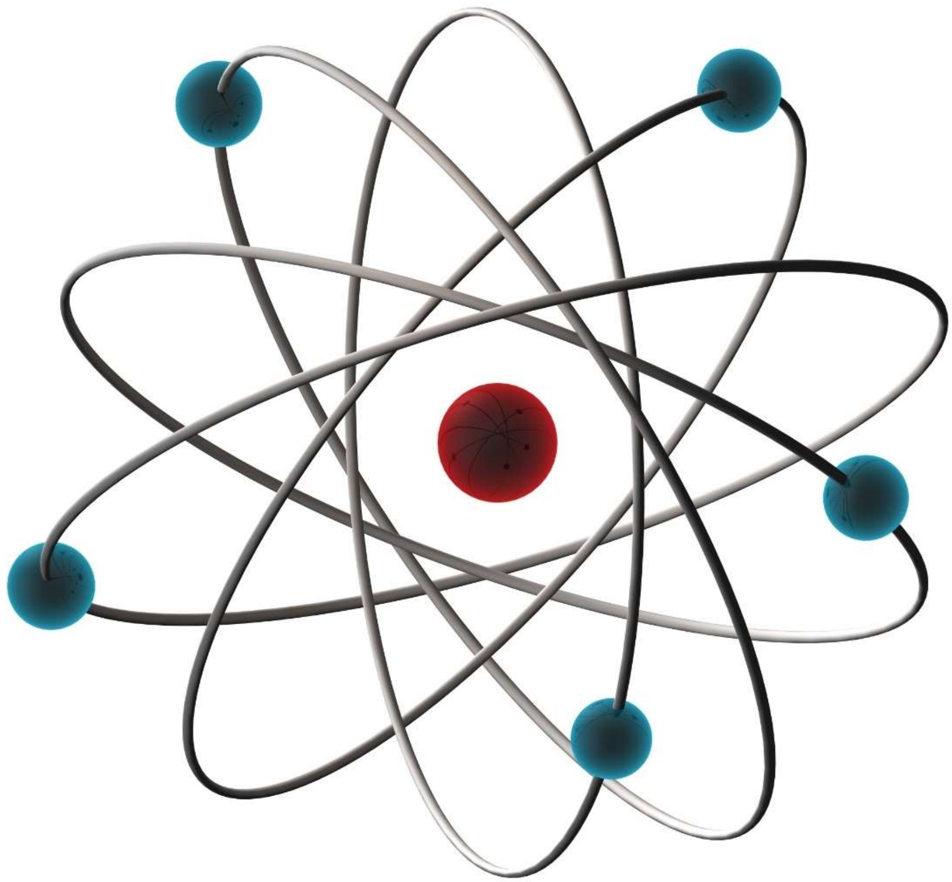


*Figure 3-6 A representation of an atom*

Democritus did not have access to the incredibly sophisticated instruments that we do today such as electron microscopes, x-rays, and laser beams to analyze the contents of material objects or to drill down to the smallest particle. As a philosopher, Democritus conducted a thought experiment using his natural senses and concluded that there must be a fundamental, indivisible particle.

## The World is Not as it Seems

The Latin poet Phaedrus said, "Things are not what they seem; the first appearance deceives many." This ancient saying can be applied to many situations, but it is very fitting to describe the way we experience the physical world and the underlying reality of the world described by physics and chemistry. We experience physical objects as solid, durable, colorful, and as existing over time. We have faith that the dining table we had dinner at last night will still be there in the morning. If the table is made of constantly moving atoms, this is not how we experience it.

## What is Mass?

According to the Cambridge English dictionary, the term “mass” means “the amount of matter in any solid object or in any liquid or gas.” What is most important in this definition is that mass is “the amount of matter in any solid object.” The definition of “matter” in the same dictionary is “physical substance in the universe.”

Putting the above definitions together, we can define mass as “the amount of physical substance in a body.” What is most important in this definition is the use of the term ‘physical.’ When Descartes defined body as “an extended thing,” he was referring to the idea that a body occupies space; it is three-dimensional. Today we would say that it has length, width, and height.

## Does “Physical” Have a Single Uniform Meaning?”

The term ‘physical,’ at least as we use it in daily life, appears to have multiple meanings. While they may both be physical in some sense, talk of rocks and star explosions that may occur in physics are very different from the term ‘physical’ as used in the language of neurology. And if we bring chemistry into the picture, matter is viewed in terms of atoms and molecules. It seems unlikely that we can use the concepts or the laws of physics and chemistry to account for what occurs in the brain, whether or not that is related in some way to what happens in the mind.

When people talk about their physical appearance, or their physical body, they are not talking about the molecular or chemical structure of their body. They are talking about the physical aspect of their person. Often “physical” in this sense is contrasted with “mind.” Philosophers have struggled to explain the relation and interaction between mind and body. The human body has its own unique laws and descriptions that cannot be completely described in the terms of chemistry and physics. A hand moving can be described in terms of muscle contractions and nerve signals, but why it moves (e.g., to wave hello) requires a framework of intentions, goals, and social context—categories that do not exist in physics. Likewise, no equation or law in physics or chemistry can express what it feels like to experience pain, hear a melody, or fall in love. We need biological concepts—like genes, organism, fitness, adaptation, and development—to make sense of life. These are not merely placeholders for underlying chemistry, but meaningful constructs in their own right.

Even trying to define a “physical object” in purely physical terms can be challenging in itself. For example, a cup is a usually round container, often with a handle, that is intended to be used for drinking. A notebook is also a physical object. However, it is a stack of pages, usually ruled and generally bound, that is used for notetaking, journaling, writing, sketching, and other ways to record thoughts, ideas, and images. Like a cup, it is a physical object, but it is defined according to its intended purpose. And even though cups and notebooks are physical objects, they are defined according to their mental purpose.

## Three Conceptions of What is Physical

It seems clear that the term ‘physical’ has at least three different senses:

1. Physical properties and entities that exist objectively and can be seen or observed by more than one person at once. These are the physical objects of our daily experience. They are considered physical in the objective sense.
2. Physical properties and entities that can be described in the terms of physics and chemistry. These are considered physical in the scientific sense.
3. Physical properties and entities that make reference to the body of a person, human being, or animal. These are considered physical in the personal sense.

### The Objective Sense of Physical

One conception of what is physical involves physical objects that can be perceived at the same time by more than one person. Examples of the use of this sense of “physical” are “I can touch this chair so it must be physical” and “This desk is a physical object.” The objective sense of what is physical is the one most commonly experienced in daily life. Objectively physical objects exist independent of any mind. An object that can be seen and touched by one person or by several people is physical in the objective sense. In daily life, we regard physical objects as being solid, stable entities that endure though time.

Objective physical objects have properties that are not describable in terms of their physics and chemistry. According to physics and chemistry, objects are not solid, but are masses of atoms, molecules, or waves. Other attributes of objectively physical objects are not translatable into scientific physical language. A desk can be beautiful, round, solid, useful, and made of wood.

Other properties such as smoothness, roughness, having a reddish color, weighing more than a computer, and having a sweet taste are examples of properties we ascribe to objectively physical objects based on our perception of them. These properties are described in terms of ordinary language and can’t be translated into scientific physical language.

There are many natural laws that govern the behavior of objects considered as perceivable objects and not as collections of atoms and molecules. These include the following:

Newton's Laws of Motion:

- First Law (Inertia): An object remains at rest or in uniform motion except insofar as it is acted upon by a net external force.
- Second Law (F=ma): The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

**Law of Universal Gravitation:** Every mass attracts every other mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

Bernoulli's principle: An increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

Laws that govern the behavior of fluids (liquids, steam, and gas) are objectively physical unless the laws describe their behavior at the atomic or molecular level.

Some objectively physical objects are defined in mental or psychological terms. The example discussed earlier of a cup as a usually round container, often with a handle, that is intended to be used for drinking. It is essential to a racquetball that it be intended to be used to play racquetball. Of course, someone might have other uses for it like playing catch with the dog. Tools such as a hammer and a screwdriver are objectively physical objects designed to be used by human beings for specific purposes.

## The Scientific Sense of Physical

Scientific physical objects are ones that can be described in the terms of chemistry or physics. What terms qualify as the terms of physics and chemistry? Some terms of physics or chemistry, such as the term neutron, are introduced originally into the language of these sciences as part of a scientific, physical, or chemical theory. Other terms, such as force, energy, and acceleration, are terms taken from ordinary language, and given a special meaning in a physical or chemical context.

There is no single rule to determine whether a term is a term of physics or chemistry. In chemistry, the best procedure is to consult textbooks of physics and chemistry and the work of physicists and chemists to determine what language they use to formulate their theories. Even the term, "the language of physics," is somewhat misleading because this language has many subsets of smaller languages. However, many examples such as atom, neutron, force, gravity, and mass are clearly terms of physics.

What entities are scientifically physical entities? These are entities that are physical, all of whose properties are scientifically physical. Examples are molecules, atoms, protons, neutrons, electrons, quarks, and gluons. These are all elements of atomic theory.

Other terms such as light wave, radiation, inertia, amplitude, entropy, and supernova are all terms of physics. Terms of chemistry include acid, alloy, element, chemical reaction, atomic mass, electrolyte, ideal gas, nitrogen, radioactive decay, subatomic particle, and viscosity.

## The Personal Sense of Physical

The human body is a living organism, and many of its qualities are designed to preserve life. Someone who doesn't eat well may become sick, while many people work hard to attain their ideal weight and appearance. When we describe someone's personally physical body we use terms like muscular, tanned, blonde, and beautiful. These terms come from the domain of personal discourse.

We also speak of a person's body as having organs such as the heart and liver, and of having perceptual organs such as the ear, eye, and nose. These are biological terms relating to the health and functioning of a human being. Our ears are personally physical objects that enable us to hear, while our eyes enable us to see. Most organs in the human body are designed around specific vital human functions.

## How the Three Types of Physical Properties and Entities Relate To Each Other

While it makes sense to think of these as three types of physical properties, they are really three different senses or meanings of the word 'physical.' One way to characterize the scientific sense is to say that it is the study of non-living matter, or the inorganic world. If we take this view, we could add some other sciences besides physics and chemistry to the list. For example, astronomy, geology, meteorology, and astrophysics all study non-living matter.

It is not implausible to say that some aspects of physics and chemistry deal with physical objects at the observable level rather than at the molecular level. Physics deals with the behavior of inorganic physical objects, their momentum, weight, and mass. It deals with the macroscopic and microscopic behavior of objects. This includes the nature and origin of gravitational, electromagnetic, and nuclear force fields. Physics looks at the origin of the universe, the nature of matter, and the speed of light. Chemistry also looks at chemicals at a macro level. It includes the study of powders, water, hydrogen, copper, and many other elements we experience in our daily lives.

### How the Mass of an Object is Defined

The British philosopher Bertrand Russell points out the difference between objects as viewed by physics and chemistry and the commonsense view of the world as containing solid objects:

> "There is…some conflict between what common sense regards as one thing, and what physics regards as an unchanging collection of particles. To common sense, a human body is one thing, but to science the matter comprising it is continually changing."

In this quote, Bertrand Russell puts his finger on what is confusing about the concept of mass. Mass is a property of physical objects in the objective sense, but it is also a property of physical objects in the scientific sense. Balls, cars, rocks, stars, and trees are all "objectively physical," and they all have mass. However, we cannot see mass; we can only observe its effects. In this respect, mass is like the wind. The mass of an object is determined by the type of molecules making up the object, their individual molecular weights, along with the number of molecules it us made up of. At another level, an object's mass is explained in terms of the "scientifically physical" number and types of atoms it is made up of. The molecular weight of the atoms making up the molecules can be determined by consulting the Periodic Table of Elements.

## Mass vs. Weight

Mass and weight are related, though distinct concepts. Mass is the amount of matter or physical substance in an object. This is determined by the type of molecules making up the object, their individual molecular weights, along with the number of molecules it us made up of. The mass of an object is independent of its location, gravity, or shape. An object with a mass of 10 kg on Earth has a mass of 10 kg on the Moon.

**Weight** is the force experienced by an object due to gravity, and it varies depending on the gravitational field strength. Understanding the difference is crucial in physics, engineering, and everyday contexts, especially when working in environments with varying gravity, such as space exploration.

Mass and weight are related by the formula:

$$W = m \times g$$

Here W = weight; m = mass; g = gravitational attraction

On earth, 10 kg weighs 9.81 Newtons, due to the force of earth's gravity. On the moon, 10 kg would weigh a lot less, due to the reduced gravitation force, even though its mass of 10 kg remains the same.

## Six Levels of What is Scientific Physical

We can take Russell's world of "continually changing matter" to mean "the world of molecular and atomic motion." There are actually six identifiable levels of what is physical, as shown in Figure 1.

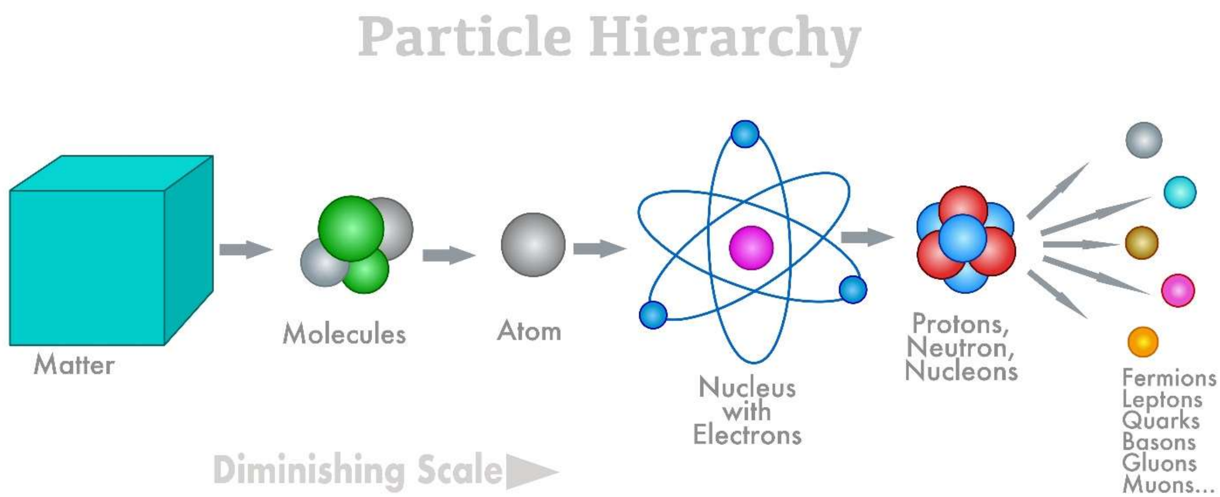



*Figure 3-7 Six identifiable levels of what is physical*

Matter is the world of objects as we experience them: solid, observable entities such as rocks, trees, stars, and our human bodies. These are made up of molecules, which in turn are made up of atoms. Atoms are made up of protons, neutrons, and electrons. Protons and neutrons are made up of quarks and other subatomic particles.

Matter is the realm of what is objectively physical. When someone defines mass as "the amount of matter in an object," they are talking about matter as we experience it with our eyes, ears, and other senses. This was Democritus' starting point when he theorized that objectively experienced matter can be divided down many times over until we reach an indivisible element. We think of objects as being made up of matter. Matter is a very broad concept in that all physical objects are made up of matter.

When Bertrand Russell says that there is a conflict between what common sense regards as one thing and physics regards as an unchanging collection of particles, he is talking about the fact that according to physics, physical objects are made up of molecules and atoms. These molecules and atoms are not static; in fact, they are constantly in motion. Figure 1 not only shows how molecules and atoms underlie and make up what we call matter, or material objects, it also shows that molecules and atoms can be further subdivided into a nucleus with protons and neutrons, surrounded by electrons, and from there into further subatomic particles like quarks and gluons.

### Emergent Properties

We can explain the relations among these six physical levels through the concept of "emergent property." An emergent property is a property of a system that arises from the interactions and organization of its parts but is not a property of the parts themselves. In other words, an emergent property is a feature or behavior of a whole system that does not exist in any individual component, and cannot be predicted just by analyzing the components in isolation. The emergent property only appears when the parts work together in an organized manner.

Emergent properties are not predictable from the properties of the individual parts. One example of an emergent property is sports fans performing "the wave," You can't understand or perceive "the wave" by studying the behavior of single individual fans. Yet the wave can be clearly perceived when the coordinated actions of groups of fans are observed. Clouds are another example of an emergent property. The shape and color of a cumulus cloud can be observed from the ground; yet the individual water droplets that make up the cloud do not have this color or shape. Fast-moving gas molecules create temperature even though no individual molecule has temperature. Still another example is the roar of the crowd at a football game. The roar of the crowd is the result of the screaming and yelling of hundreds and often thousands of fans. Yet listening to one fan does not yield this roar; it is only the collective action of many fans that generates "the roar of the crowd."

### A Ladder of Emergent Properties

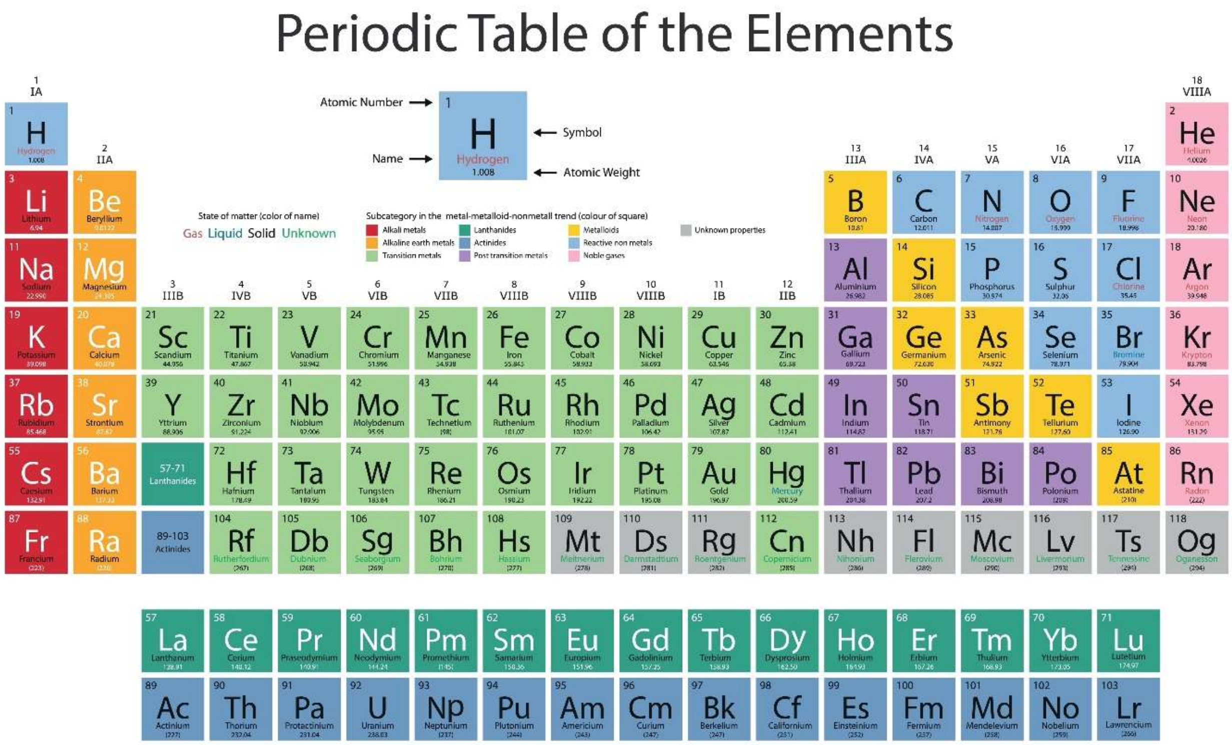
The properties of solid objects we perceive in real life are emergent properties of the molecules and atoms that make them up. Because the atoms are moving so fast, they create the appearance of a solid object. The molecules and atoms themselves are not solid, but when they move at such a high rate of speed, they create the appearance of solidity. A similar thought experiment explains the other levels in the diagram. Molecules are an emergent property of the constituent atoms in motion that make them up, and atoms are an emergent property of the motion of protons and neutrons and the surrounding electrons. Protons and neutrons are an emergent property of quarks, gluons, and other subatomic particles.

The world is not as it seems. What we find when we look beneath the surface is a hierarchy of particles that are built on each other (see diagram above). Today scientists believe that Democritus' indivisible particles are not his atoms, but subatomic particles such as quarks. Beginning at the bottom with subatomic particles, we can build a "ladder of emergent properties" until we reach the stable, solid objects of our everyday experience.

### A Hierarchy of Particles

In the above discussion, we have drilled down to get to the most elemental concept of mass. If we now build back up, we can say that the much of the mass of protons and neutrons derives from the near light-speed movement of the high speed quarks and gluons. The mass of an atom derives from its nucleus, which is made up of protons and neutrons. The more protons and neutrons an atom has, the more mass it has. By referring to the Periodic Table of Elements, we can determine how many protons it has. This is its atomic number. For example, hydrogen, with an atomic number of 1, has only one proton. The Periodic Table is ordered according to the atomic number of the elements in the chart. Carbon, with an atomic number of 6, appears to the right of hydrogen, while oxygen, with an atomic number of 8, appears to the right of carbon.

**Figure 3-8**




While the number of protons in an atom remains constant for the type of element it is, different atoms of the same element can have different numbers of neutrons. For example, Carbon-12 has six protons and six neutrons, while Carbon-14 has six protons and eight neutrons. An atom's mass number represents how many protons and neutrons atoms of this type have. Carbon-12 has six protons and six neutrons and has a mass number of 12. Carbon-14 has six protons and eight neutrons and has a mass number of 14. These different variations of carbon atoms are called isotopes. Like carbon, other atoms also have different isotopes.

The Periodic Table also contains the atomic mass of each element. The atomic mass of each element is the weighted average of the masses of all the isotopes of an element, taking into account their frequency of occurrence. The isotopes of an element have different atomic masses because they have different numbers of neutrons.

## Molar Mass

Atoms combine to form molecules. The mass of a molecule is the sum of the masses of the atoms it contains. For example, water has the formula $H_2O$, meaning that one molecule of water contains two hydrogen atoms and one oxygen atom. We can determine the mass of one molecule of water by summing up the masses of two hydrogen atoms and one oxygen atom. However, the molecular weight of molecules may vary, depending on the component isotopes. Oxygen has three stable isotopes, along with several short-lived ones. Oxygen's atomic mass value in the Periodic Table takes these isotopes into account. Oxygen-16 is by far the most common oxygen isotope for oxygen.

While atomic mass represents the mass of atoms, the mass of molecules is called molar mass. The unit of measurement for molar mass is g/mol, meaning grams per mole. A mole is a unit that represents $6.022 \times 10^{23}$ particles (atoms, molecules, ions, etc.). This number is called Avogadro's number. This huge but important number helps us bridge the gap between the world of molecules and the objective world of our experience.

What is the molar mass of one molecule of water? We can calculate this by using the atomic mass of hydrogen and the atomic mass of oxygen. A molecule of water has two hydrogen atoms and one oxygen atom. Using the Periodic Table of Elements, we find that the hydrogen's atomic mass is 1.008. Oxygen's atomic mass is 15.999. Therefore, we can compute the atomic mass of one molecule of water using the following formula:

(Atomic mass of hydrogen x 2) + the atomic mass of oxygen

This works out to be the following formula:

Hydrogen (H) g/mol = 1.008 x 2 = 2.016 g/mol

Oxygen (O) g/mol = 15.999 g/mol

Total molar mass of $H_2O$ = 18.015 g/mol

When calculating molar mass, the common practice is to use the atomic weights listed in the Periodic Table and not be concerned about molecules containing particular or different isotopes. If a particular molecule contains a unique isotope, the molar mass could be calculated by using the atomic mass of that isotope rather than the atomic mass listed in the Periodic Table.

## The Mass of Water

What is the value of knowing the molar mass of water? The SI unit for mass flow measurement is kilograms/second. This gives us a way to work down from a mass flow measurement in kilograms per second to the number of molecules being measured. This can be done using the following steps:

1. Convert kilograms/second to grams per second. 1 kg = 1000 grams. For example, if the mass flowrate is 0.25 kilograms/second, convert this to 250 grams/second.

2. Convert grams to moles, using the molar mass of water:

Moles per second = (250 g/sec)/(18.015 g/mol) = 13.877 mol/s

3. Convert moles to molecules, using Avogadro's number:

13.877 mol/s x 6.022 x $10^{23}$ = 8.36 x $10^{24}$ molecules/s

## Understanding What Mass Is

The above demonstration shows that we can convert any mass flow measurement of water in kilograms per second into a measurement of the number of molecules flowing in a unit time. This can be done for any fluid if we know the molar mass. What are the implications for our understanding of what mass is?

Previous discussion showed that the mass of molecules amounts to the mass of the atoms making up those molecules. Among the 118 elements of the Periodic Table, there is a wide range of atomic mass values. These values are determined by the number of protons and neutrons in the nucleus of the atoms. The heavier atoms have many protons and neutrons, while the lightest one, hydrogen, has only one proton. Electrons and binding energy only play a very small role in an atom's mass.

As discussed previously, protons and neutrons are made up of even smaller particles called quarks. However, the mass of the quarks only accounts for about 1% of the mass of the proton. Most of the proton's mass arises from the interaction between the quarks, gluons, and other particles that are held together by the strong nuclear force. These particles moving at incredible speeds and the energy they generate are the ultimate source of mass in protons and neutrons. This means that energy is the ultimate source of mass.

What does this tell us about what mass is? The mass of a proton is generated by the energy of the subatomic particles inside the proton. A proton has tremendous energy inside it from the interaction of quarks, gluons, and other subatomic particles. These particles are held together by the strong nuclear force. Yet the proton doesn't have a specific boundary or "skin" holding all these elements in – the internal particles are prevented from "flying out" and are held in place by the strong force that binds them together. This explains why protons, atoms, and even molecules can move at relatively slow paces compared to the near light-speed of the subatomic particles within the proton. Despite all the incredible energy inside the proton, it has a boundary that keeps it together as an entity. Even though this boundary is not well defined, it serves to mark the edge of the proton.

A proton is like a hurricane in many respects. A hurricane is held together by its eye, its eyewall, and by the rainbands of clouds and thunderstorms that spiral outward from the eyewall. Like the proton, a hurricane isn't enclosed in a physical boundary. Instead, the edge of a hurricane is marked by the area where the violent storms that are part of the hurricane dissipate and where the winds fall below hurricane force.

## Mass Defined

What is mass? Earlier in this chapter I cited the Cambridge English dictionary definition of "mass" as "the amount of matter in any solid object or in any liquid or gas." We can now define mass as follows.

From a scientific point of view, mass is determined by the amount of matter in a solid, liquid, or gas. The mass of a substance is measured in molar mass, which is the molecular weight in grams of one mole of that substance. The molar mass of a substance is given by the molecular weight of the molecule that makes up the substance in atomic mass units. In the example of water given above, its molar weight of 18.015 g/mol is a result of the atomic weights of hydrogen and oxygen. This molar mass is the sum total of the atomic weights of the atoms and molecules that make it up.

The unit of measurement for molar mass is grams or kilograms. Some substances are heavier than others. For example, hydrogen is the lightest element with an atomic weight of 1.008. Oxygen, by contrast, has an atomic weight of 15.999 g/mol. The differences in mass among different substances is explained by the different atomic weights of their constituents and by how many of those constituent molecules each substance has.

What makes up the protons and neutrons is the fields of energy created by the interactions of quarks, gluons, and other subatomic particles moving at near light-speed and colliding with each other. These subatomic particles are contained in the protons or neutrons of the atoms that make up matter and are held together by the strong nuclear force. The fields of energy that are created by the interactions of subatomic particles are the primary source of mass in the protons and neutrons. The speed with which atoms and molecules move creates the emergent and objective world of matter that we experience as objects in solid, liquid, or gas form.

From an objective (experiential) point of view, we experience physical objects and fluids made of matter. “Matter” is a general term used to designate what makes up any physical object, entity, or fluid. While we don’t experience molecules and atoms directly, it is their varying atomic weights and molar masses that account for the differences in the objects we experience. Weight and mass are related but distinct. Objects with greater mass will weigh more because gravity pulls more heavily on their mass.

Another way to describe mass is as inertial mass, which quantifies the resistance of an object to changes in motion. This resistance to change in motion in a solid, liquid, or gas is created by its atomic and molecular mass. The amount of resistance to change in motion is proportional to the atomic weight and molar mass of a substance. Ultimately, the amount of resistance to change is determined by the strength of the field of energy created by the high-speed motion of the subatomic particles in the atomic and molecular structure.

## The Bridge between the Objective World and the Scientific World

Earlier in this chapter, we cited the following quote from Bertrand Russell:

> "There is…some conflict between what common sense regards as one thing, and what physics regards as an unchanging collection of particles. To common sense, a human body is one thing, but to science the matter comprising it is continually changing."

We can now see that what Russell was referring to as "one thing" is the solid objects in the objectively physical world. When he says that the matter comprising it is constantly changing, he is referring to objects in the scientifically physical world. This is the world of molecules, atoms, neutrons, electrons, and subatomic particles. This world is a hierarchy of emergent properties. The objects that we experience are emergent properties of the molecules and atoms that make them up. These atoms and molecules are emergent properties of the protons, neutrons, and electrons that make them up. The protons and neutrons are made up of quarks, gluons, and other subatomic particles. When these quarks, gluons, and other subatomic particles move at near light-speed within the protons and neutrons, they generate the emergent property of mass, which becomes the mass of the protons and neutrons. These subatomic particles are held together by the strong nuclear force.

The fields of energy created by the motion of subatomic particles is the primary source of the emergent property of mass in the protons and neutrons and in the atoms and molecules that they make up. These fields of energy are the ultimate source of mass in the object that we perceive in the objectively physical world and that is made up of the atoms and molecules that make up this object in the scientifically physical world.

### A Bridge Between Mass Flow and the Scientific Physical World

The demonstration of the way to work down from the unit of mass flow, kilograms/second, to the number of molecules being measured provides a bridge between mass flow as we experience it and the scientific world of molecules and atoms. When we measure mass flow in a fluid, we are measuring its resistance to flow as determined by its molecular structure. Coriolis meters determine mass flow by measuring how much a vibrating tube is deflected by the inertia of a fluid. The force or momentum of the fluid is proportional to its mass, and this determines the amount of deflection, giving us mass flow. The mass of the fluid is determined by the atoms and molecules that make it up in the scientifically physical world.