Part 1: What is Physical Science?

Chapter 1: An Introduction to Physical Science

1. The function of science
   a. Man’s search for answers.
      i. How did the world come to be as it is?
      ii. Why did the world come to be as it is?
   b. Science attempts to answer these questions, as do “junk” science and religion.

2. The difference between physical and social science.
   a. Examples of physical sciences: physics, chemistry, meteorology, biology.
   b. Examples of social sciences: sociology, economics, psychology. Social sciences attempt to explain and predict human behavior.
   c. This division is artificial, inasmuch as all science is at base physical science. Indeed, everything is physics. Chemistry is generalized physics. Even psychology is physics. (Although psychology could in theory be done at the atomic level, we wouldn’t make much progress if we tried to do it that way.)
   d. Two things make social science special:
      i. The presence of the Feedback Effect. In the social sciences, making a prediction affects the outcome of the prediction. When economists predict a stock-market crash, it affects the chance that there will be a stock-market crash, inasmuch as people respond to the prediction. This doesn’t happen in physical science. Our predicting the weather doesn’t affect the weather.
      ii. Ethical concerns. There are lots of social science experiments it would be nice to do but we can’t do, because humans have rights. Does eating a diet of fattening foods cause heart disease? Does exposure to violence as children make people more violent as adults?
   e. At Wright State we teach PHL 471 (the philosophy of physical science) and PHL 472 (the philosophy of social science.) We do this for historical reasons, but if we had it to do over, we probably wouldn’t do it this way.

3. “Junk” science
   a. It would be one thing to be simply ignorant of science—to have to say, “I don’t know,” to a number of scientific questions, but some people are instead willfully misinformed. They are fans of junk science. (Ghosts. Mind reading. Astrology. The healing power of crystals.) When real scientists attack junk science, it only serves to whet some people’s appetite: if real scientists don’t like it, it must be true.
   b. Junk science is popular in part because it is easy. You can have learned no science at all since fourth grade and still be an expert at junk science in a matter of minutes: “They say crystals have healing power. They aren’t sure why, but they think crystals gather and focus energy.” And junk science is fun. Instead of talking about, say, the chemical composition of ocean water, you get to talk about ghosts. And rarely in junk science do you have to do math.
   c. Real science takes considerably more effort, but the results are worth that effort. The findings of
science are not just interesting, they are often astonishing. Along these lines, consider again our discussion of where you came from.

4. The features that distinguish “True Science” from religion and junk science.
   a. True Science is **reasonable**. It assumes that things are the way they are for a reason, and that it therefore makes sense to ask why-questions. Furthermore, in True Science, why-questions are never answered with “just because.”
      i. Consider a pebble on a beach. True Science assumes that there is a reason why it is there. More precisely, it is there because the universe is subject to certain physical laws and because certain events took place in the past. Scientists may not know exactly why the pebble is there, but they nevertheless assume that it is there for a reason.
      ii. Many of the reasons True Science gives involve causal explanations. True Science is deterministic: it assumes that “every state of affairs is the inevitable consequence of antecedent states of affairs.” Nothing “just happens”; to the contrary, everything that happens has a cause.
         (1) A consequence of determinism: suppose you bring a certain system into an initial state and allow nothing external to the system to intrude. You then watch and see what happens to that system. If you return the system to exactly the same initial state it will behave exactly the same as it did before. If it behaves differently, a scientist will conclude that either the initial state of affairs was different or something external intruded into the system.
   b. The explanations offered by True Science are **evidence-based**. Scientists care very much about how their theories connect up with the actual world. For this reason, they spend a considerable amount of time observing the world to see what is out there before they attempt to generalize or theorize.
      i. Aristotle (384-322 B.C.) declared that large objects fall faster than light ones, and for nearly two millennia most people accepted this claim. Galileo (1564-1642) actually tried the experiment, and found that they fall at the same speed. Galileo was a True Scientist; Aristotle was not.
      ii. When scientists find evidence that contradicts their laws and theories, they don’t ignore it or reject it out of hand. They at least worry about it and maybe change their views because of it.
   c. The explanations offered by True Science are **testable**. In particular, they are falsifiable, meaning that it is possible to do an experiment or make an observation that will refute them. (Notice that a good scientific theory is one that, although falsifiable, has not been falsified.)
      i. Most people, when they believe something, go out of their way to defend it; scientists, when they believe something, go out of their way to disprove it. All of the explanations offered by science are falsifiable. Indeed, pick any explanation that today is accepted by the scientific community; it is conceivable that tomorrow scientists will do an experiment or make an observation that will show this explanation to be incorrect.
      ii. An example of a statement that is not testable: There is an invisible armadillo on my desk. (By “invisible,” I mean that the armadillo not only can’t be seen, but can’t be heard, felt, tasted, or smelled, and cannot be detected by any scientific instrument.) This statement is not falsifiable. Does it follow from this that it is true?
      iii. An example of an untestable theory: the Theory of Divine Providence. According to this theory, whatever happens is God’s will. Even if something unaccountable happens, one can say that it was God’s will that it happen that way.
         (1) The Theory of Divine Providence can explain whatever happens. This might seem like a desirable feature of a theory, but we need to keep in mind that a theory that
explains everything explains nothing. Unless there are things that, according to a theory, can’t happen, the theory will not be falsifiable and therefore will not count as a true scientific theory.

iv. Many people think the goal of science is to come up with theories that can’t be disproved. They reason that if a theory can’t be disproved, then it must be true. True Science, however, goes out of its way to come up with theories that can be disproved. Indeed, a True Scientist, after proposing a theory, will typically describe experiments which, if they turn out a certain way, will refute his theory. Scientists spend far more time testing theories (and trying to disprove them) than they do developing the theories in question.

v. Some things to keep in mind about falsifiability:
   (1) Science allows theories that are very difficult to disprove; it does not allow theories, like those just described, that cannot possibly be disproved. If a theory cannot possibly be disproved, scientists don’t conclude that it is true; to the contrary, they conclude that it is, from the scientific point of view, nonsense.
   (2) Although scientists favor theories that are falsifiable—that in theory can be disproved—they reject theories that have been falsified—that have been disproved.

d. Scientists readily admit their fallibility.
   i. They go to great lengths to avoid mistakes in their own work.
      (1) When scientists are testing a new drug, they do a double-blind study.
         (a) The research subjects are “blind” in that they don’t know whether they are being given the drug or a placebo.
         (b) But more importantly, the researchers are “blind” as well: they don’t know which subjects are being given the drug and which are being given the placebo. (An “outside party” keeps track of this information.)
            (i) This is to prevent them from behaving differently toward the patients who get the drug from those who do not; such differences in behavior can affect the efficacy of, say, a drug to treat depression.
            (ii) This also prevents them from being subconsciously biased when they observe their subjects to determine whether the drug they are testing is more effective than a placebo.
         (c) A good scientist will readily admit that his own biases and desires can affect the outcome of an experiment or observation and will therefore be perfectly willing to take steps to avoid this phenomenon.
         (d) A proposed experiment to test the healing power of prayer. Find 100 people who are sick of the same fatal disease. Divide them randomly into two groups. Have a network of people pray for those in one group. Don’t do this for the other group. Keep the groups in the dark about whether or not they are being prayed for. Then see if there is a difference in the mortality rates of the two groups.
      (2) Scientists spend considerable effort trying to find their own mistakes before they publish a paper.
      (3) Scientists spend considerable effort trying to find the mistakes of other scientists and the scientific community as a whole.
         (a) The best way to become a famous scientist is to find a mistake that all other scientists are making!
            (i) The rest of the scientific community will defend itself against your criticisms, but if the evidence is in your favor and you fight hard enough, they will ultimately agree with you (or retire or die, and be replaced by younger scientists who will readily accept your views).
This is what happened when Einstein proposed his theory of relativity in 1905. He declared that physics was mistaken in thinking that time was absolute and that things that moved very fast were bound by the same laws of physics as things that moved slowly. He described experiments physicists could do and observations they could make to test his theories. They did the experiments in question and made the observations, and found, much to their surprise, that Einstein was right.

Science is enormously contentious. At any given moment, there are very many heated debates going on in the scientific community. Students are often unaware of this, since they are exposed to a scientific theory only after the debates have been won. (Science textbooks are filled with “consensus” views.)

Much scientific progress has come about because scientists admit their own fallibility and try hard to find their own mistakes! Compare this with religion, in which “the truth” was declared long ago, and those who question this truth are excommunicated or worse.

The theories offered by True Science enable us to make meaningful predictions, that something will or won’t happen. The reason True Science is useful—and far more useful than junk science—is that it lets us predict the future and thereby lets us know what is going to happen in the future.

This ties in with testability. A testable theory will generate predictions that might turn out false. An untestable theory like the Theory of Divine Providence (according to which, whatever happens is God’s will) will not generate predictions about what is going to happen.

Notice that if a new theory makes a radical prediction—one that currently accepted theories say can’t be correct—and if this radical prediction turns out to be correct, it will be powerful evidence in favor of the new theory.

Einstein’s theory of general relativity said that light could bend in the presence of a strong gravitational field; the accepted theories of the time said it could not. During a solar eclipse in 1919, astronomers looked for the bending of light that Einstein had predicted, and when they found it, many physicists switched their allegiance to Einstein’s theory.

The importance of precise predictions. True Science makes astonishingly precise predictions. An astronomer, for example, might predict the position of the moon in the sky a thousand years from now to within a fraction of a degree. Junk science, by way of contrast, makes predictions, but most of them are either vague or ambiguous.

Examples of vague predictions:
(a) The writings of Nostradamus (1503-1566). He is said to have predicted Chernobyl, the death of Princess Diana, and the 9/11 attacks. The problem is that the predictions are stated “poetically.” Here is the passage in which he “predicts” the role Hitler would play in World War II: “Beasts wild with hunger will cross the rivers / The greater part of the battlefield will be against Hister.” The claim is that “Hister” is a misspelling of “Hitler.” Because they are stated vaguely, it is invariably only after events take place that people figure out what it was that Nostradamus predicted. The predictions are therefore useless.
(b) Fortune cookies. (They often don’t tell fortunes; they give advice.)
(c) Religion allows at best vague predictions about the future: There will be a Second Coming . . . sometime.

An example of an ambiguous prediction—that is, a prediction that has two interpretations: King Croesus (died in 546 B.C.) asked the Oracle of Delphi whether it
would be a good idea to invade Persia. The Oracle predicted that if he invaded Persia, “a great kingdom will be destroyed.” Croesus invaded Persia, and his own kingdom was destroyed. Notice that no matter how things turned out, the Oracle could claim success.

f. True Science is impersonal.
   i. Only magicians can do magic. Only oracles can foretell the future. Only a true believer can talk to God. Only witches can cast spells. By way of contrast, anyone can do science, although a person may have to work hard to learn enough to do it.
   ii. Compare the development of a scientific theory with the revelation of a new religion. The person who reveals a new religion typically claims that God has spoken to him. We have no way to confirm or disconfirm what he says God has told him. His status with respect to the religion is therefore special. When, on the other hand, a scientist comes up with a new scientific theory, he has to explain to us the observations and experiments that led him to draw the conclusions he drew. After he has stated the theory, we don’t need him any more. He has no special status with respect to the theory, although we may admire him for having developed it.
   iii. When scientists report their observations or experiments, they tell what others have to do to make the same observations or perform the same experiments: True Science is replicable.
      (1) It isn’t enough for an experiment to be replicable by the same scientist; other scientists must be able to replicate it.
      (2) Notice that although all experiments should be replicable, some observations might not be. In this case, it helps if a scientist has filmed the phenomenon or the entity he observed.

5. Because it has the above characteristics, True Science has been far more successful, in practical terms, than religion or junk science. True Science makes many useful predictions about what the world will be like tomorrow; religion and junk science cannot do this. True Science has produced a series of useful inventions; religion and junk science have produced none at all. Religion may offer solace, and junk science may offer fun, but True Science produces useful practical knowledge in a way that religion and junk science cannot.

6. Some qualifications regarding the above remarks about True Science.
   a. I said that True Scientists never accept “just because” as an answer to a why-question. As a matter of logic, though, there must be some questions to which the only possible answer is “just because.” For example, there is probably no reason why light travels at $3 \times 10^8$ meters per second. It just does. Its traveling at this speed represents a fundamental, unexplainable fact about the universe.
   b. I also said that True Science is deterministic—that whatever happens has a cause. Quantum physics might be an interesting exception to this claim.
Chapter 2: What Scientists Do

1. Scientists **describe** the world. We can distinguish between two sorts of descriptive activities: **observation** and **experimentation**.
   a. Scientists **observe**.
      i. They look to see what exists.
         (1) Do black holes exist? Planets that orbit stars other than the sun? Ivory-billed woodpeckers?
      ii. They examine the **properties** of the things that exist.
      iii. They make observations across time to see whether the things that exist cease to exist, whether new things come into existence, and whether the properties of the things that exist change. (Maybe rocks only exist in summer; maybe they fall during the day but rise at night.)
      iv. They make observations across regions of the planet and the universe to see whether the things that exist are distributed regionally and whether they have different properties in different regions. (Maybe rocks fall in the northern hemisphere, but rise in the southern; maybe granite exists only on earth.)
   b. Scientists **experiment**.
      i. The difference between observations and experiments: In doing an experiment, we **manipulate** the world in some way to see what happens; in making an observation, we observe the world **without manipulating** it. Astronomy is an observational science: astronomers observe the universe without manipulating it. Chemists, by way of contrast, do experiments: they mix chemicals to see what happens. If we watch things fall, we are observing; if we pick things up and drop them to see what happens, we are experimenting.
         (1) A scientist who relied only on observation (and refused to experiment) would be slow to find out about the world. Does granite fall if dropped? He would have to wait for an avalanche to find out.
   c. It is important to note that when scientists observe and experiment, they do so in a “directed” manner. A scientist who sets out to count the grains of sand in the Sahara Desert is making observations, but they would be pointless. A scientist who maps the sand dunes of the Sahara Desert is also making observations, but they are potentially useful. The conclusion: some observations are more useful than others.

2. Scientists **interpret** their observations. This involves categorizing and generalizing.
   a. **Categorizing**. Examples of categorization: A botanist divides plants into different species. An astronomer divides stars into different types. A geologist divides rocks and land forms into different types. A meteorologist divides clouds into different types. A chemist divides chemicals into different types.
   b. **Generalizing**. Anyone making observations quickly discovers the presence of **regularities**. These regularities are known as **laws of nature**.
i. One famous law of nature is Galileo’s Law:

\[ s = 16 \times t^2 \]

where \( s \) is the distance (in feet) that an object will fall in time \( t \) (in seconds) after being released. This law doesn’t look like a universal generalization, but it is a disguised universal generalization. What it really says is, “For any dropped object, \( s = 16 \times t^2 \).”

ii. Another law of nature: ice melts at 32 degrees Fahrenheit.

iii. Yet another law of nature:

\[ E = mc^2 \]

where \( E \) is energy, \( m \) is mass, and \( c \) is the speed of light.

c. Notice that in interpreting their results—in categorizing and generalizing—scientists are telling us how the world is, but they aren’t explaining why the world is the way it is. After they have told us that there are different species of animals, we can ask why this should be; and after telling us “Any solid object, when released near the surface of the earth, will fall \( 16 \times t^2 \) feet in \( t \) seconds,” we can ask why objects fall and why they fall at this particular speed. In order to explain why the world is the way it is, scientists go on to develop theories. A law of nature describes a regularity; a theory explains why the universe is regular in this way. (We will have more to say about theories in a moment.)

3. Scientists make predictions. Once scientists have discovered regularities and stated them as laws, they are in a position to make predictions. For instance, a scientist who knows that “Any solid object, when released near the surface of the earth, will fall \( 16 \times t^2 \) feet in \( t \) seconds” can predict that if he drops a rock from a ledge 64 feet high, it will take the rock 2 seconds to hit the ground. It is science’s ability to predict the future that, for most people, makes it valuable: we like to know what is going to happen tomorrow.

4. Scientists invent. On the basis of the regularities they discover, scientists invent machines that can exploit these regularities. (This is applied science.) People who have no interest in advanced physics for its own sake often have an intense interest in the inventions made possible by the discoveries made in advanced physics.

5. Scientists explain. Finding a regularity gives rise to a variety of why-questions. Why does this regularity hold? Why not some other regularity? Why is it that solid objects, when released near the surface of the earth, fall \( 16 \times t^2 \) feet in \( t \) seconds? Why not fall \( 13 \times t^2 \) feet in \( t \) seconds, or \( 16 \times t^3 \) feet in \( t \) seconds? Indeed, why does it fall at all? Why not rise?

a. A scientific hypothesis is an “educated guess” about how the world is or about how things work in the world.

i. An example is the “hygiene hypothesis,” according to which the increased incidence of asthma among citizens of industrialized nations is due to their having been raised in unnaturally clean environments. Some scientific hypotheses are subsequently borne out by observations and experiments, but most are abandoned.

ii. Nearly a hundred different hypotheses have been offered about how the dinosaurs died, but only about half a dozen of them are still “in play.”

b. Scientists develop scientific theories to answer these why-questions. It is one thing to say that different chemicals exist; it is another to develop a theory of why chemicals exist at all, and why, given that they exist, they come in differing types. It is one thing to say that objects, released near the surface of the earth fall; it is another to explain why they fall. Theories are an attempt to answer the why-questions that arise after we observe the world around us. Why is it this way?
Why isn’t it some other way?

i. A theory can be thought of as a “mature hypothesis.” It will have more evidence in support of it, and be more widely accepted in the scientific community than a hypothesis.

ii. The word “theory” is used in many ways. Many theories don’t attempt to answer why-questions. In this course, I am interested in a special subclass of theories, namely, those that do attempt to answer why-questions. I shall refer to these theories as scientific theories.

iii. Scientific theories often explain things and phenomena we can directly observe in terms of things we can’t directly observe. These latter entities are called theoretical entities.

c. Some examples of scientific theories:

i. **Atomic theory** holds that matter, which is visible, is composed of atoms, which are not. Atomic theory allows us to explain many everyday phenomena, like why different substances have different chemical properties. Atoms (and the electrons, neutrons, and protons of which they are composed) are examples of theoretical entities.

ii. **Germ theory** explains observable phenomena like colds in terms of entities—germs—that can’t be directly observed.

iii. The **theory of gravitational attraction** explains phenomena we can observe, like falling objects, in terms of things we can’t directly observe, like gravitational fields.

d. Some scientific theories answer why-questions about the past. Geologists have developed theories about what must have happened in the past to give us the landforms we see around us. Astronomers have developed theories about what must have happened in the past to give us the universe we see around us. Biologists have developed theories about what must have happened in the past for the earth to be inhabited with the various species.

6. **Scientists test theories.** Once scientists have developed a theory, they use it to make predictions and then they check (by making observations or doing experiments) to see whether the predictions are correct. (This is the second time that observations and experiments come into play in the scientific process.) In junk science, by way of contrast, there is little interest in testing theories to see if they are correct.
Chapter 3: The Laws of Nature

1. What is a law of nature?
   a. The laws of nature are not laws that have been enacted or decreed (although some religions argue
      that God “decreed” the laws of nature). Rather, they are statements that express regularities in
      nature.
   b. The laws of nature are different from the laws of mathematics and logic.
      i. A mathematical law: The commutative law of addition tells us that for any x and y,
         \( x + y = y + x \).
      ii. A logical law: The law of the excluded middle tells us that for any statement P, either P or
         not P.
      iii. The laws of mathematics and logic express necessary truths: they can’t be false. The laws
         of nature, by way of contrast, express contingent truths about our universe: they could be
         false (the laws of nature could have been otherwise than they are) but are in fact true.
         (1) Even God is bound by necessary truths. Miracles are violations of the laws of nature,
         but not the laws of logic. Not even God can violate the laws of logic.
   iv. The difference between laws of nature and definitions. The statement that a yard is equal to
      36 inches is true because of how we define the words “yard” and “inch,” not because of
      anything about the physical nature of the universe. Notice that we do not make observations
      to establish the truth of this statement; instead, we consult the dictionary.
   c. Some laws of nature can be expressed qualitatively:
      i. “Bowling balls released near the surface of the earth fall straight down.”
      ii. “Burn carbon in the presence of oxygen, and carbon dioxide is produced.”
   d. Other laws of nature can be expressed quantitatively.
      i. We have already encountered three quantitative laws:
         (1) Galileo’s Law: \( s = 16 \times t^2 \), where \( s \) is the distance (in feet) that an object will fall in
             time \( t \) (in seconds) after being released.
         (2) “Ice melts at 32 degrees Fahrenheit.”
         (3) “\( E=mc^2 \),” where \( E \) is energy, \( m \) is mass, and \( c \) is the speed of light.
      ii. Quantitative statements of laws are preferable to qualitative statements, since they are more
          precise, but it isn’t always possible to state a law of nature quantitatively.
      iii. Often when we state laws of nature quantitatively, they will involve constants. In Galileo’s
          law, for example, the number 16 appears as a constant; in the equation \( E=mc^2 \), \( c \) is the speed
          of light, which is a physical constant. One important activity of science, beside discovering
          the laws of nature, is to determine the exact values of the constants associated with those
          laws.

2. Laws of nature are expressed in the form of universal generalizations—that is, they have the form
   “All A’s are B’s.” The statement “All crows are black” is an example of a universal generalization.
   a. As stated above, Galileo’s Law is a disguised universal generalization. The proper statement of
      Galileo’s Law is this: “All dropped objects fall at the rate \( s = 16 \times t^2 \).” Likewise, the proper
      statement of the law that “Ice melts at 32 degrees Fahrenheit” is this: “All samples of ice melt at
      32 degrees Fahrenheit.”
   b. Not all true universal generalizations will be laws of nature.
      i. Consider the following statements:
         (1) “Everyone in this room is wearing clothes” and
         (2) “All samples of ice melt at 32 degrees Fahrenheit.”
      ii. Both are universal generalizations and both are true. The former is an example of an
          accidental generalization, though. Only the latter would count as a law of nature; it is true
not by accident, but because of the way the world works.

c. The difference between laws of nature and simple facts about nature. The claim that this is a sample of ice or that this sample of ice melted at 32 degrees Fahrenheit are facts about nature, not laws of nature.

3. We can distinguish between laws of nature that are universal and those that are restricted. A universal law of nature holds true everywhere in the universe; restricted laws of nature hold true only in some parts of the universe or under certain conditions.
   a. The law that “All dropped objects fall at the rate \( s = 16 \frac{t^2}{2} \)” is restricted: it holds true at the surface of the earth, but not on the surface of the moon or Jupiter.
      i. And even on different points on the surface of the earth, the “constant” in this law will vary. This is because gravity is stronger at some places than others. (See the map 2/3 of the way down on this page: http://discovermagazine.com/2007/mar/grace-in-space/article_view?b_start:int=1&C=)
   b. An example of a universal law of nature is Newton’s Universal Law of Gravitation: \( F = \frac{GMm}{r^2} \), where \( F \) is the gravitational attraction between an object of mass \( M \) and an object of mass \( m \), \( G \) is the gravitational constant, and \( r \) is the distance between the two objects. The law holds not just on the surface of the earth, but everywhere in the universe. Furthermore, the Gravitational constant \( G \) is truly constant.
      i. This terminology is a source of possible confusion: a universal law of nature is a law of nature (and therefore a universal generalization) that is universally true—that is true, in other words, throughout the universe.
   c. Often, it will be possible for us to derive restricted laws of nature from universal laws of nature. If we know the mass of the earth, for example, we can derive Galileo’s Law from Newton’s Universal Law of Gravitation. This last law is therefore more powerful than Galileo’s Law.
   d. Some laws of nature are restricted, in that they make a number of assumptions about a phenomenon and will therefore apply only under certain circumstances. Consider, for example, the law that water freezes at 32 degrees Fahrenheit.
      i. Supercooling: a liquid is chilled to below its freezing temperature without becoming a solid. This might happen because the water lacks nucleation sites.
         (1) Instant frozen beer: http://www.youtube.com/watch?v=n_H5ZJoZSBo . This beer has been cooled in a freezer till its temperature is just below 32 degrees. When the beer is tapped, bubbles form, which act as nucleation sites, and the beer freezes “instantly.”
      ii. Likewise, it isn’t always true that water heated to 212 degrees Fahrenheit will boil. It depends, to begin with, on the atmospheric pressure over the water. (At high altitudes, water boils at temperatures less than 212 degrees, requiring the use of pressure cookers to cook things.) And even if water is at standard atmospheric pressure, it will not boil if the water lacks nucleation sites. For an illustration of superheated water, see http://www.youtube.com/watch?v=ZAgqpDF4bVw . In this demonstration, distilled water (which, because it has been distilled, lacks nucleation sites) has been heated in a microwave to above 212 degrees without boiling. Once a source of nucleation sites (sugar?) is added, the water instantaneously boils. (Don’t try this at home! You can get badly scalded!)
      iii. Also, water boils at different temperatures at different altitude.s

4. It is misleading to refer to something as a law of nature, for all of these “laws” might be mistaken. What we should instead call them is “our best current guess regarding the regularities in nature” or “very well established hypotheses.”
   a. This is why scientists, after discovering a law of nature, keep testing it. Scientists are acutely aware that what they now believe to be true might turn out to be false. (Notice that in religion, people are not likewise open to the possibility that their most fundamental religious beliefs might
5. Some questions about the laws of nature:
   a. How do we know that a law is truly universal? How do we know that at the far side of the universe, the same laws apply as apply here?
      i. Astronomical observations tell us that this is so.
   b. How do we know that the laws of nature were the same in the past as they are at present?
      i. The light from distant stars was produced in the distant past and therefore gives us information about what the universe was like back then.
   c. But if you put these two comments together, you see that what astronomical observations show us is that in the past, the laws of nature were the same at the far side of the galaxy as they now are on earth. For all we know, the laws that currently apply at the far end of the galaxy are different from those that now apply on earth.

6. Physical constants. We have seen that constants appear in many laws of nature.
   a. Some important physical constants:
      i. c = the speed of light
      ii. G = the gravitational constant
      iii. \( \mu \) = the ratio of a proton’s mass to that of an electron
      iv. e = the elementary charge
   b. Scientists do experiments to establish the exact value of these constants.
      i. The history of attempts to measure the speed of light.
         (1) Galileo tried to establish the speed of light using flashing lanterns. To understand this experimental technique, think about how you could determine the velocity of sound. (Notice that in using this technique, you are assuming that light travels much faster than sound.) Galileo’s conclusion: light travels too fast to be measured by this crude technique.
         (2) In 1676 Ole Romer used the motions of Jupiter's moons to come up with a rough approximation of the speed of light.
         (3) In 1849 Armand Fizeau used a rotating toothed wheel to determine the speed of light. He would shine a beam of light through an opening, off a distant mirror, and then back at the wheel. If the speed of the wheel is just right, the wheel will have moved one “notch” during the time the light was traveling, and it will be visible to the observer.
         (4) This experiment was soon improved upon by Jean Foucault, who used a spinning mirror instead of a toothed wheel.
         (5) At the turn of the twentieth century, physicists discovered (much to their surprise!) that the speed of light is the same for all observers, regardless of whether they are moving toward or away from the source of light. This discovery set the stage for Einstein’s theory of relativity.
      ii. Scientists have chosen to define the speed of light as being exactly 299,792,458 meters per second and to “adjust” the length of a meter so that light will travel 299,792,458 meters in a second. More precisely, a meter is defined as the distance light travels in a vacuum in \( \frac{1}{299,792,458} \) of a second.
   c. Are the constants in fact constant?
      i. Some have argued that \( \mu \), the ratio between the mass of a proton and the mass of an electron is changing.
      ii. Others have argued that the speed of light used to be slower.
   d. An interesting question: why do the physical constants have the values they do?
      i. As we shall see, if you change the physical constants even slightly, you dramatically change
our universe.

ii. Some think that the physical constants have the values they do “just because”: it is simply a basic fact about our universe that they have the values they do. Others (including physicist Lee Smolin) have offered explanations of why, if we humans are to exist in order to talk about them, the physical constants must have the values they do.