gravitation and acceleration implies many strange predictions (such as light waves bent by gravitation), but again, Einstein had the intellectual courage to follow through, though the mathematical difficulties prevented him for many years from producing a satisfactory theory.

The problem that Einstein really wanted to solve—an explanation of the quantum nature of matter and energy—eluded him completely. Max Planck had shown that energy is emitted and absorbed from matter as if it existed only in discrete units called quanta, and later, Einstein himself had extended the idea to show that that light itself was quantized. Despite years of work, he was never able to explain why this should be so, and it was left to other physicists to work out the quantum structure of the atom. If there is an explanation for his failure to produce a theory of quantum mechanics, it is possibly that his courage failed him here, because every attempt led to weird results that even Einstein could not accept, though today they form a major subject in the undergraduate physics curriculum.[17]

Einstein lived hand-to-mouth throughout his studies and for many years afterward, until finally in 1909 he received an academic appointment at the University of Zurich. He was an accomplished violinist and quite sociable. Unlike Newton, Einstein was a "ladies' man," marrying and divorcing twice as well as carrying on affairs. His first wife Mileva Marić Einstein (1875–1948) also studied physics and mathematics, but eventually Einstein cut her out of participation in his research, leaving her to raise the children like a traditional housewife. Mileva (or her lawyer) was sufficiently vigilant to write a clause in their divorce agreement stipulating that should he should win the Nobel Prize, the money would go to her; and so it did when he won the prize in 1921.

5 Pseudoscience: What Some People Do Isn't Science

In chapter 2 we defined a scientific theory and showed that there are claims about the universe that are not scientific. Scientists certainly recognize the existence of fields of human activity like art or religion that are not considered to be within the province of science, and these fields do not necessarily conflict with science. Far more insidious to science and society is the widespread phenomenon called *pseudoscience*. Pseudoscience involves the use of the style and trappings of science for claims that cannot by any stretch of the imagination be called science. In this chapter, I would like to analyze some of the more popular pseudosciences, in order to show why they are not part of the body of science.

Pseudoscience as the precursor of science

Many pseudosciences are frozen artifacts of earlier periods. Before the advent of modern science they were considered scientific, and they retain their ancient doctrines unchanged and unaffected by the achievements of the past few centuries. It is as if followers of pseudosciences would prefer a noisy, expensive, low-precision, heavy, mechanical calculator from the early twentieth century to our quiet, cheap, high-precision, pocket-sized, electronic calculators.

Alchemy was the progenitor of chemistry, as astrology was of astronomy. The benign nature of highly diluted homeopathic concoctions did far less damage than did the medical practices of the eighteenth century like blood letting and purging. Furthermore, many of science's greatest heroes engaged in what is today called pseudoscience. Newton spent years working on alchemy, and Galileo cast horoscopes, including one cast on January 16, 1609, predicting long life for Ferdinand I de Medici, the Grand Duke of Tuscany. Proponents of astrology, especially those who like to bask in the scientific prestige of Galileo, will be sorry to learn that Ferdinand died just twenty-two days later![1]

One of the characteristics of pseudoscience is the almost religious-like canonization of the writings of the "elders." As one nearer the age of the "elders" than the "youngsters," I can appreciate that with experience comes a modicum of wisdom that you wish you had decades ago. But there is no reason to believe that today we are any less intelligent and competent than people who lived hundreds or thousands of years ago. On the contrary, while we respect and admire the achievements of the pioneers of science, the accumulation of knowledge over the centuries gives us a better perspective in which to view the world.

A scientific theory is *never* justified solely, or even primarily, by appeal to authority. At most, authority is deferred to for convenience: since science is so extensive that you cannot be familiar with all the details of all subjects, you have to accept the word of authority concerning outside your specialty. Nevertheless, there is quite a lot of similarity in the way science is practiced across its specialities, so that you can usually judge which authorities are reputable and how to resolve conflicts between them. But under no circumstances is a scientific theory ultimately judged by the stature of its creator or supporters. If a young student doesn't accept Einstein's theory of relativity, she is not told to shut up and refrain from desecrating the memory of one of the most revered scientists of all time; instead, she is quietly shown the direction to the library and invited to read and reread his papers, to check and recheck his calculations and arguments, and to examine and reexamine the experiments that provide confirmation for the theories.

Science and its history

Before continuing the discussion of pseudoscience, let us further analyze the relation of science to its history.

One of the central debates concerning the teaching of science has to do with the place of the history of science in the curriculum. Should science be taught *ahistorically*? That is, should science be taught by simply presenting theories, observations, and experiments, without regard to the historical process of discovery, rich in colorful characters, mistakes, and controversy? Physics can be taught by simply presenting the various theories of gravitation, thermodynamics, and electromagnetism without ever mentioning the names of Isaac Newton, Sadi Carnot (1796–1832), and

James Clerk Maxwell. Darwin's name could be totally forgotten without doing any damage to biology. Many people oppose this approach, because science is part of the human story and should be told as such. Furthermore, if students are shown the challenges facing these pioneers and their struggles to create modern science, perhaps they can put their own difficulties in perspective and persevere in their studies. Regardless of whether you accept or reject the idea that history is an essential part of science education and even of science itself, it seems clear that scientific *results* are universal and hence ahistorical. If advanced extraterrestrials exist and if contact is ever made with them, we have reason to expect that they would know about gravitation and relativity and quantum mechanics, even if they had never heard of Newton and Einstein and Schrödinger.

The ahistorical nature of the results of science, as opposed to the reverence accorded the writings of the pioneers of pseudoscience, is clear when you realize that the actual writings of the pioneers of science are today totally ignored, except by historians and by a few scientists and educators with an interest in history. Newton's *Principia* is simply not accessible to today's scientists. If you insist on reading the original, there is a book that is in effect an exegesis of the original text.[2] The reason that the *Principia* and other works of the period on physics are inaccessible is that they are couched in the mathematics of classical geometry. For example, Galileo provides an elaborate geometrical argument that the integral of x is $x^2/2$, which is a result of elementary calculus that is taught in high school these days.[3] Calculus, the mathematical innovation of Newton and Leibnitz, took quite a long time to develop and was only given a good theoretical foundation in the late nineteenth century.

The dynamic nature of science is clearly demonstrated by the fact that Darwin's extensive written works are outdated and are not used in routine scientific work. Despite the fact that extensive research in the life sciences is carried out at my institution, a search of the online catalog for a copy of *On the Origin of Species by Means of Natural Selection* sent me, not to the well-stocked and bustling life-sciences library, but to the musty historical collection, tucked away in a seldom-visited library. I found and borrowed a one-hundred-year old copy of the *Origin*; reading it through, I was more than once forced to cut through the uncut edges of the pages, which had not been consulted since its publication! Of course, there is no reason for a practicing biologist to consult the *Origin* as part of his routine scientific

work, though he may want to do so out of an interest in the historical foundations of his field. The basics of Darwin's theory are accepted as fact and there is no need to work through hundreds of pages of his argument, in particular, Darwin's fascination with artificial selection as practiced by farmers and pigeon enthusiasts. The *Origin* is not used as a textbook in evolutionary biology, because essential aspects of the theory like genetics and molecular biology did not exist at that time, and the book contains many incorrect attempts at answering problems whose solution came only later.

A comparison of *Origin* with a modern textbook on evolution is instructive.[4] The latter covers the basics of evolution fairly quickly and even the fossil record—the target of incessant attacks by creationists—is not surveyed in great depth. While fossils are extremely important in that they provide the raw material for the reconstruction of the phylogeny of life, the details are left to professional paleontologists, because the evidence that fossils provide for the theory of evolution is uncontroversial. On the other hand, chapter after chapter is devoted to the mathematics of population genetics, controversies about the principles of the classification of species, and explanations of the molecular basis of genetics. Darwin may have pioneered the subject of evolution, but to call it "Darwinism" is today a misnomer, because evolution is a dynamic science that has expanded so far beyond what Darwin could have imagined that he would fail a modern examination in the subject without years of further study.

So when you are told that the wisdom of the ancient Greeks proves the truth of astrology, or that alchemy must be true since it was practiced by a great scientist like Isaac Newton, or that you must consult the pioneering opus on homeopathy written two centuries ago by Samuel Hahnemann (1755–1843), you are justified in concluding that you are dealing with a pseudoscience. Science is dynamic as new experimental techniques are developed, new theories are proposed, and new connections are found between disciplines. Some subspecialties become unproductive and uninteresting, while new ones command interest and inspire scientists to commit time and resources to their study. Together with new notations and pedagogical techniques, these changes are reflected in an unending stream of new textbooks.

Over the line of demarcation

Suppose now that a pseudoscience drops its canon and saints, and attempts to present itself as a dynamic, modern science. How can we distinguish it from science? The answer is that the principles of a science must conform to the definition of a scientific theory, above all, the requirement that the theory explain and predict phenomena. This means that the cumulative corpus of observations and experiments must confirm the theory, not falsify it. Even if occasional experiments support a pseudoscientific claim, they can be considered as coincidences that are likely to emerge randomly. Empirical evidence must be *cumulative*, *continuing*, and *unambiguous*.

It is often claimed that such experiments are not performed or are suppressed because of prejudice or a conspiracy among scientists or others. Does anyone really believe that the granting of a PhD degree in science is conditional on a mafia-like blood oath, in which you promise not to perform research on a list of pseudosciences specified by a godfather? (If there was such a ceremony, I must have missed it.) Everyone knows that a successful conspiracy should be limited to a handful of people; it could never successfully encompass the thousands of new students granted PhD degrees in the sciences every year. Presumably, such a conspiracy would have to be enforced by blackmail and murder, and we would be regularly treated to sensational headlines (sidebar).

Conspiracies in Science

CalTech Researcher Found Shot Ten Times
Lured to an abandoned warehouse in LA
FBI suspects she was using CalTech computers
for astrological calculations
and was close to a revolutionary breakthrough
Director of Research at CalTech Held for Questioning

In fact, the scientific community is quite diverse and unfettered. If there were the slightest reason to believe that there is some scientific validity to astrology, some graduate student or faculty member somewhere would be more than eager to achieve fame, and perhaps even a Nobel Prize, by performing research on the subject. Even funding need not be a problem, although it is claimed that "alternative" therapies are never tested because

giant pharmaceutical companies are worried that such remedies will bite into profits on patentable drugs. Annual sales of homeopathic remedies are in the hundreds of millions of dollars (though they are still a fraction of the sales of conventional remedies).[5] Scientific proof of the efficacy of homeopathic remedies would cause their sales to sail through the roof, which is ample justification for companies manufacturing the remedies and venture capitalists to invest in research grants to pay for the labs and graduate fellowships necessary to carry out such a research program.

So why are scientists so obtuse as to reject lines of research arising from pseudoscience? The provocative philosopher of science Paul Feyerabend (1924–1994) wrote angrily about a large group of scientists who signed a petition against astrology, although it was clear that they knew nothing about it. The reason for the reluctance of most scientists to investigate pseudosciences is not prejudice or a conspiracy, but the absence of the other elements that characterize a scientific theory—conciseness, coherence, and mechanism. A serious scientific research program often requires years or decades to carry out, so before committing yourself to such an undertaking, you have to have not just enthusiasm, but also some reasonable expectation of success.

We will now examine astrology and homeopathy to see if they are consistent with our definition of a scientific theory.

Why astrology is a pseudoscience

What exactly does the "theory" of astrology consist of? The basic claim is that the positions of the "planets" within the "constellations" at the time of your birth determine, or at least strongly affect, your nature and your personality, as well as the events of your future life. The first problem with a putative theory of astrology is that it cannot be written on a sweatshirt. For each planet, each constellation, and each possible relationship between them, there is a different "law." No other laws in the universe work this way. In physics, gravitation, quantum mechanics, and relativity operate uniformly on all objects of the universe. In fact, Einstein's amazing achievement was to reduce the number of primitive concepts by identifying mass with energy and gravity with acceleration. In biology, it has been established that the entire genetic code in DNA is composed of only four different molecules called nucleotides, and their arrangement controls the

synthesis of only twenty different amino acids from which all proteins are constructed, so biology too can be written on a sweatshirt. Calculating the motion of a particle or specifying the biological function of a protein may be exceedingly complex, but the theories themselves are concise. If astrologers really want their claims to be considered as science, they will have to come up with something that would concisely explain what makes for "Jupiter-ness" or "Gemini-ness."

More serious, however, is the lack of coherence in astrology. I purposely put the words "planet" and "constellation" in quotation marks above, because these are purely conventional. The word planet means "wanderer," because these apparently star-like objects were observed to move relative to the immense number of other stars, which just rose and set together. Once upon a time, it was believed that there were only five such planets—Mercury, Venus, Mars, Jupiter, and Saturn—because only these can be discerned by the unaided eye. Unfortunately for astrology, three more planets have since been discovered: Uranus, Neptune, and Pluto.

Now, to be consistent, either every horoscope prior to the discovery of these planets was in error because it did not take into account the influence of the planets, or, the three new planets are irrelevant and should be ignored. But astrologers can neither disparage their ancestors by insisting that the new planets are important, nor can they supply a reason why Uranus, Neptune, and Pluto should be ignored, while Saturn continues to influence us.

In fact, the situation is even more problematic. Shouldn't the hundreds of thousands of asteroids be taken into account? The asteroid Ceres, at 933 kilometers in diameter, is over one-third the size of Pluto and since it is relatively near the Earth, its influence should be many times stronger that of Pluto. Pluto itself is now known to be one of a group of planet-like objects called the *Kuiper belt*, though almost nothing is known about individual planets of the group. When a future spacecraft does identify them, will astrology have to be reset again?

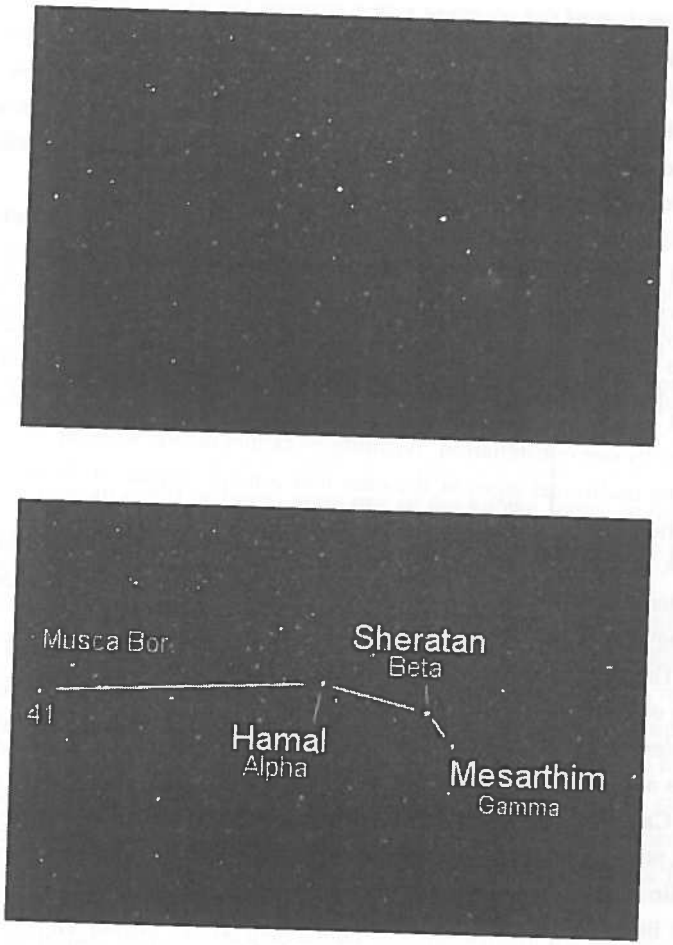
Since writing the previous sentence, a Kuiper belt object called *Quaoar* has been identified. Quaoar is one-half the size of Pluto and thus presumably influences our destiny, though it will take years to analyze its orbit. Of course for a scientist, this ambivalence does not exist, because "planet" is simply a term used for convenience. You may argue whether Quaoar is a planet or not, but for a scientist, what counts is not the specific term used,

but the scientific characteristics of the object: its mass, orbit, and composition. It does not matter one bit whether any particular object is called a planet or a moon or an asteroid or a Kuiper-belt object, and there is not a single aspect of astronomy or astrophysics that depends on "Jupiter-ness" or "Quaoar-ness."

As for the constellations, they have *no* physical meaning whatsoever. A constellation is simply a two-dimensional projection of a subset of the bright stars in a three-dimensional sector of the sky. Individual stars in a constellation may be thousands or tens of thousands of light years distant from each other, and they may be of widely differing sizes and temperatures, because a small, weakly radiating star may appear bright and thus significant simply because it is relatively nearer.

Consider for example, the constellation *Aries*. The top photograph on the next page shows the constellation, but you would have a hard time picking out the stars that compose it unless someone points them out as on the bottom photograph.[6] (Musca Borealis, the "Northern Fly," refers to an obsolete constellation that no longer exists in the IAU list [see below].) With a lot of imagination, you might be able to see a Ram in the four stars. But consider the distances of these stars from us: Mesarthim is 204 light years away, Sheratan is 60 light years away, Hamal is 66 light years away, and 41 Ari is 160 light years away. From a vantage point in the universe "off to the right" of our position, you might still be able to see Sheratan and Hamal, but the other two stars would be out of your field of view. Ascribing "Ram-ness" to these four unrelated stars is totally arbitrary and meaningless, unless you believe that the Earth is a privileged vantage point. But that puts you back into the pre-Copernican dark ages.

The number of constellations and their boundaries is totally arbitrary. The arbitrariness is reinforced when we note that people of other civilizations (for example, the Chinese) saw a different number of constellations and gave them entirely different forms and meanings.[7] Scientists use an official list of 88 constellations adopted in 1930 by the International Astronomical Union (IAU). The twelve constellations of the Zodiac are of somewhat more interest than others, because the Sun and the planets appear to pass through them, though, of course, the Sun and planets are much, much nearer the Earth than the stars forming a constellation. Astrologers should perhaps explain what makes *Aquarius*, *Gemini*, *Leo*, and *Taurus* so special, and why they neglect their cousins *Boötes*, *Camelopardalis*, *Fornax*, and *Puppis*. ("Hi! I'm a *Camelopardalis*. What sign are you?")



The definition of a constellation is based upon ancient observations performed with the unaided eye; now that telescopes have been invented, the projection of the region of space attributed to a constellation will contain hundreds or thousands of other stars that could not have been observed before its invention. There is no a priori reason to assume that these stars have less influence on our lives than the ones that are interpreted as forming the constellations simply because they were easy for the Greeks and Babylonians to see.

Since the stars are moving with tremendous velocities, the two-dimensional projection changes over time, so the constellations are not an "eternal" characteristic of the universe. In fact, because of a wobble of the Earth's axis called *precession*, the relation of the constellations of the Zodiac to the Earth is continuously changing, completing a full revolution in about 26,000 years. So roughly every 26,000 / 12 = 2,167 years, your sign moves by one constellation. Astrologers cannot decide whether you should use the traditional signs or the ones that actually appear in the sky on the traditional dates of the year.

A further difficulty is that according to the IAU boundaries, there are fourteen constellations in the Zodiac, invalidating (or not) traditional astrology based upon twelve constellations.

The most basic and central concepts of astrology turn out to be a remnant of the Earth-centered worldview that was demolished by Copernicus, Kepler, and Galileo hundreds of years ago, yet the "theory" of astrology does not take this new knowledge into account.

Can astrology explain and predict, accurately and precisely? Astrological predictions are notoriously vague and lack precision. As for accuracy, while any aficionado of astrology will be happy to provide you with countless instances of anecdotal evidence, empirical studies of the accuracy of astrological predictions have consistently failed to demonstrate any statistically significant accuracy.[8]

The lack of conciseness and coherence and the inability to explain and predict feed off each other. If astrology were in fact a science, then the question of the influence of the outer planets or of the Earth's precession would be decidable from empirical evidence. Simply take large samples of people, cast their horoscopes with and without each of the factors, perform a statistical analysis of the result and obtain the answers. Over a relatively short period of time, perhaps ten or twenty years, the preponderance of evidence would lead to a conclusion that would be accepted by the entire community (or at least by most of its members). Astrology cannot be a science because it lacks the dynamics of a science: theoretical proposals and experimental results leading to a (perhaps temporary) consensus of what is known and what is not. Instead, each astrologist decides what techniques and assumptions to use, which clearly shows that astrology is a belief system like a religion, not a science.

The lack of mechanism in astrology

One of the most important reasons why scientists reject pseudosciences is that they lack even the semblance of mechanism. For astrology to be a scientific theory, there must be some mechanism that explains the effects of the planets and the constellations on the newborn baby. The mechanism must be sufficiently powerful and long lasting so they permanently affect the individual's nature and personality, and influence events decades later. This mechanism could be based upon one of the known forces in the universe, or perhaps there might be an unknown force. Let us first examine the known forces in the universe.

There are only four known forces in nature. Two, the force of gravity and the electromagnetic force, are familiar to all of us. The other two are simply called the strong and weak forces; these forces function within atomic nuclei, binding together neutrons and protons, as well as binding the subparticles from which they are formed. Interactions with these forces cannot take place at distances greater than an atomic nucleus, so they can be ignored by the majority of humankind that does not engage in elementary particle physics. Let us consider in turn if either the electromagnetic force or the force of gravity could provide a mechanism for astrology.

Electromagnetism can be discounted as a mechanism for astrology. It is true that this force is probably the most significant force in our lives because it is the mechanism of chemical interactions, including biochemical interactions. We know, for example, that exposure to x-rays can have serious biological effects, and even the microwave radiation from a cell phone has a biological effect, though there is controversy over whether the effects are clinically significant.

Magnetic fields have much less biological effect, so little in fact, that *magnetic resonance imagery (MRI)* scans are considered to be extremely

safe, even though massive magnetic fields are employed. The field of an MRI scanner can be as high as 2 Tesla, which is 40,000 times the strength of the Earth's magnetic field that measures 0.00005 Tesla! In turn, by the time they reach us from space, the magnetic fields of the stars are minute compared to the field of the Earth. Any dangers inherent in an MRI scan come not from the magnetic field itself, but from the effect of the field on metallic devices. For example, a boy was killed when a steel oxygen tank was accelerated into the scanner, and others have been killed or injured due to the effect of the magnetic field on pacemakers and other implanted devices.[9] If astrology claimed that the locations of MRI machines in a hospital determine a newborn baby's personality, the claim might be worth investigating, though all evidence supports the view that even strong magnetic fields have little effect on the body.

Electromagnetic force is transmitted by photons, which travel at the speed of light. There is simply no way that photons sent hundreds or thousands of years ago from the various stars composing a constellation could effect a baby. This radiation is so weak that large telescopes have to be built to detect it and, in a technological tour de force, the Hubble Space Telescope was launched to detect radiation that would otherwise be attenuated or scattered by the Earth's atmosphere. Furthermore, the planets that are so important in astrology do not emit photons, but merely reflect a very small fraction of photons that come from the Sun. If photons could have such an effect, then surely we must consider local sources that bombard the baby with innumerable photons. The baby's astrological chart should take into account the placement of the lights in the delivery room, the type of bulbs, the color of the uniforms of the doctors and nurses, the time of day, and the degree of cloud cover. These should all affect the baby's personality by an enormously greater factor than the positions of the planets.

Consider also that the frame of an ambulance acts as a *Faraday cage*, insulating those inside from the effects magnetic and electronic fields. (The Faraday cage effect explains why frequent strikes of lightening on airplanes do not affect the passengers inside.) If the mechanism of astrology were based upon electromagnetic effects coming from the stars and planets, it would be impossible to cast a horoscope for a person who was born inside an ambulance! Reputable astrologists would have to inform their clients of this complication and inquire into the construction of their places of birth, as a building constructed of reinforced concrete would attenuate the

Mesmerism and Magnetism

Magnetism is intensely appealing to pseudoscientists. I suppose that that is because it is the only real, well-known force that appears to be mysterious and can thus be endowed with mystical powers. In the waning years of the ancien régime of prerevolutionary France, a German physician named Franz Anton Mesmer (1734–1815) claimed to be able to cure disease by manipulating "animal magnetism." His treatments became fashionable and trendy, provoking a backlash that led to the establishment of a committee including such luminaries as American diplomat and scientist Benjamin Franklin (1706–1790), pioneering chemist Antoine Lavoisier (1743–1794), and physician Joseph-Ignace Guillotin (1738–1814). Their report from two hundred years ago is a marvelous example of a well-designed scientific investigation; it totally debunked Mesmer's claims.[10] It is surely unfair that Mesmer's name lives on in the verb "mesmerize," while Lavoisier had his head chopped off by a machine named after Dr. Guillotin.

electromagnetic influence more than a wooden house. Astrologists simply cannot explain why a few measly photons from stars that cannot even be seen in an urban area have any biological effect whatsoever.

The situation with gravitation is similar. We may find the force of gravity to be overpowering when we have to get out of bed in the morning, but in fact, gravitation is an extremely weak force, so weak that a puny magnetized screwdriver can easily overcome the force of gravity exerted on a screw by the Earth, a gigantic sphere composed of dense rock and metal. Astronomers Roger Culver (1940–) and Philip Ianna have great fun computing and comparing gravitational forces.[11] The force of gravity exerted by the obstetrician is far greater than the sum of the gravitational forces exerted on the baby by all the planets and stars in the universe combined! If gravitation were a significant factor, then presumably a young mother should be told something like: if you want your baby to become a scientist, ask the obstetrician to stand to your left, though if you want him to become a musician, ask her to stand on your right.

So the only possibility that we are left with is that astrological effects are caused by some unknown force. While this position may have been tenable in the time of the Greeks, in our day this is simply nonsense, because

the four forces have been studied in great detail and they are able to account for almost all phenomena known in the universe. The remaining "gray areas" concern subatomic particles and the conditions that existed during the first millionth or billionth of a second following the big bang theory. While it is conceivable that an unknown force may exist, it is simply inconceivable that a force exists whose *only* effect is upon the personality and future of humans, and whose effect is determined at the moment of birth.

The assumption that there exists an unknown force with biological implications leads to too many unanswerable questions: Why does it influence a 3 kg baby at the moment of birth and not a one-cell zygote at the moment of conception? (Presumably to avoid asking your parents embarrassing questions and exposing delicate family secrets.) Since all mammals are biologically very similar, is a dog's personality influenced by the stars and planets? (Yes! An Internet search of "dog astrology" yielded almost 100,000 hits.) Well, how about a mouse or a cockroach or a tomato or a bacterium? Precisely the same molecular processes have been shown to occur in all life forms, so why should the unknown force be different. All the discoveries about the universe portray a totally different situation of universal laws that affect all objects identically, whether they are animal, vegetable, or mineral.

They laughed at Galileo

At this point, one expects to hear something like: "They laughed at Galileo, too," meaning that forces were unknown until they were discovered, and that pioneers were laughed at by the stodgy scientific establishment. Presumably, astrology will be vindicated some day. However, this is a total misrepresentation of the history of science. First of all, no one laughed at Galileo; the Inquisition would not have bothered itself persecuting clowns and jesters. Galileo was persecuted precisely because his advocacy of the Copernican system *was* convincing and was considered a threat to the theology and political interests of the Roman Catholic Church at that time. Great scientific discoveries are not necessarily immediately accepted, but the transition period from disbelief to acceptance is relatively short, a few decades at most, as scientists perform experiments and work out implications of a theory, until the preponderance of evidence convinces scientists to accept the theory. Novel ideas are just too interesting to ignore. If there were any reason whatsoever to believe that there is an unknown force that can function as a mechanism for astrology, scientists would compete for the honor of discovering the details.

If there is in fact a fifth force, it will be discovered during some scientific experiment, and it certainly won't fit the shaky edifice of an ancient system, just as the development of modern chemistry grew out of experimentation and theory building and never justified the claims of alchemy. Scientists refuse to study astrology, not because of prejudice or because there is a conspiracy afoot, but simply because there is not a shred of evidence that would justify the expenditure of valuable time from a career.

Could there be a mechanism to explain homeopathy?

Homeopathy was developed by Dr. Samuel Hahnemann (1755–1843). He based his method of treatment upon the *Law of Similars*: Disease can be cured by ingesting extremely small amounts of substances that in large doses cause symptoms similar to the disease in healthy individuals. I won't present a analysis of homeopathy to the depth of the previous analysis of astrology, because the essence of the analysis is the same: Homeopathy does not possess any of the characteristics of a scientific theory except for its outer trappings.[12] However, it is worth discussing one aspect, namely, the mechanism.

In the eighteenth century, there was nothing a priori impossible about the Law of Similars. In the context of the medical knowledge at that time, it was conceivable that during the ensuing decades a mechanism would have come to light. However, precisely the opposite occurred.

From chemistry, the study of molecules and their interactions, we now know that at the incredibly high dilutions used in homeopathic remedies, most pills or elixirs will not contain even a single molecule of the purported active ingredient. Recognizing this, homeopathy dropped its chemical claims in favor of a theory that the water retains a "memory" of the active ingredient. For this to be taken seriously, there must be a plausible mechanism that explains how molecules of water store the memory of the extract of duck liver or whatever it came into contact with before being diluted. The discussion of the impossibility of mechanism in astrology applies here too. There are only four forces known to nature and the ex-

istence of a fifth whose effects appear only as required by homeopathy is nonsense. H_2O is a very simple molecule and its physics and chemistry have been well understood for decades. Water is water and there is no place for a "memory" to hide in the structure of the molecule.

The impossibility of obtaining a biological effect from extremely diluted solutions becomes apparent when compared with the concentrations of other substances that must be ingested in order to produce a measurable effect. Some people believe that conventional medicines are harmful and avoid them, but a glance at their dosages furnishes a guide as to what amount of a drug can actually cause an effect on a human body. Headache pills contain 500 milligrams of the active ingredient and tranquilizers typically contain from 1–5 milligrams; each milligram contains billions upon billions of the molecules required to cause a clinical effect. Even "native" remedies like the bark of the willow and the cinchona trees were eventually analyzed and found to contain large quantities of real active substances: aspirin and quinine.

Pathogens face the same hurdle. We remain healthy in the presence of the millions and billions of bacteria and viruses we come into incessant contact with in our environment. Only when the exposure passes a certain level can bacteria and viruses overcome the natural and effective immune system of the body.

To get a feel for the numbers, look at the *Foodborne Pathogenic Microorganisms and Natural Toxins Handbook* (affectionately known as the *Bad Bug Book*) published by the Center for Food Safety and Applied Nutrition of the US Food and Drug Administration.[13] For *Vibrio cholerae*, the pathogen that causes the terrible and often fatal disease cholera, an infective dose—the number of bacteria that you have to ingest to become ill—is one million! Additionally, during the incubation period, the bacteria will rapidly reproduce until extremely large numbers are churning out toxins at sufficient concentrations to produce the symptoms. Put another way, you could drink an elixir containing 10,000 cholera bacteria and nothing should happen to you. (To be on the safe side, don't try this at home!) So how can you even conceive of one single molecule curing a disease when it takes a million bacteria to cause it? It just doesn't make sense.

Conversely, it is not the minute amount of weakened bacteria or viruses in a vaccine that protects you, but the massive amount of antibodies produced in reaction by the immune system. These antibodies are detectable

in modern lab tests and this mechanism is an essential part of the scientific justification that was not available to Hahnemann's contemporary Edward Jenner (1749–1823) who first performed vaccination for smallpox.

We see in homeopathy the same characteristics that led us to classify astrology as a pseudoscience: the reverence for elders overcoming the lack of predictive success and the refusal to deal with contradictions between the putative underlying explanatory mechanisms and newly discovered knowledge about the basic sciences.

The waste of pseudoscience

To the extent that people pursue pseudosciences as a hobby or diversion, the practice is harmless. Many of the tricks used by pseudoscientists can be mastered in the course of learning to be a magician.[14] Certain pseudoscientific practices can be beneficial if they give people the spiritual comfort, psychological support, or relief from psychosomatic ailments that comes from having someone listen attentively to your problems.

The problem begins when pseudosciences are not satisfied with their status as belief systems and claim a scientific mantle that they do not deserve. As noted long ago by David Hume (1711–1776):

> The knavery and folly of men are such common phenomena, that I should rather believe the most extraordinary events to arise from their concurrence, than admit of so signal a violation of the laws of nature.[15]

Enormous resources are invested in pseudoscience that could be better invested in improving the health and education of the public. Furthermore, the advice given by pseudoscientists frequently causes real damage to those who seek its advice. One only has to think of the tragedies that can occur if one's choice of a mate is dictated by astrological signs; the process is sufficiently unreliable as it is that to deliberately introduce additional randomness is unconscionable.

Finally, this travesty of science is particularly saddening because it seduces talented young people into dedicating their lives to a charade when they could be more satisfactorily employed elsewhere in science, education, or health care (though probably with less remuneration). We can only hope that education will eventually triumph over pseudoscience as Charles Mackay vainly hoped over 170 years ago:

> It is to be hoped that the day is not far distant when lawgivers will teach the people by some more direct means, and prevent the recurrence of delusions like these, and many worse, which might be cited, by securing to every child born within their dominions an education in accordance with the advancing state of civilization. If ghosts and witches are not yet altogether exploded, it is the fault, not so much of the ignorant people, as of the law and the government that have neglected to enlighten them.[16]

* * *

Pseudosciences fail to comply with most or all of the characteristics of a scientific theory. They are rarely concise and coherent, and almost never expressed in mathematical laws. Pseudoscientists studiously ignore any discrepancies between their predictions and the real world, attributing such failures to bad auras emanating from skeptical observers. If a mechanism is supplied, it is invariably in the form of a mysterious energy field, undetectable by any other means. One can only marvel at the audacity of pseudoscientists who blithely purvey the wildest fictions as science.

Louis Pasteur: Serial Scientist

Louis Pasteur (1822–1895) did not have the luck to be born into a well-to-do family like Charles Darwin. He was an extremely talented artist, and it is not farfetched to imagine that if circumstances had been different, he might have become as famous as other nineteenth-century French artists. While not an outstanding student, Pasteur was, nevertheless, sufficiently talented that his teachers predicted that he could become a college professor, and his parents made the effort to send him to the prestigious Ecole Normale Supérieure in Paris. Pasteur studied chemistry and obtained a doctoral degree, performing pioneering studies on crystals. He was able to show that the compound tartaric acid existed in two independent forms, one left-handed and one right-handed.

By 1854, Pasteur was professor of chemistry at the industrial city of Lille in northeastern France. He was asked to look into difficulties in the fermentation of alcohol from sugar. Sometimes, a batch of solution undergoing fermentation produced the desired alcohol and sometimes the result was unpredictably spoiled. In a series of experiments, Pasteur was able to demonstrate that fermentation is a *biological* process, and that alcohol is the waste product of the digestion of sugar by cells of yeast. The spoiled batches were the result of similar action by other microorganisms. The technique he invented for preventing the spoilage of food—heating to destroy microorganisms—is called *pasteurization* in his honor.

We sometimes talk of a serial criminal compelled to repeat his crimes; Louis Pasteur's biography is that of a serial scientist, compelled always to seek out new problems to solve, and his talents led him to a series of pioneering investigations. The foray into fermentation marks the beginning of Pasteur's work in biology, which led him out of his official speciality, chemistry. Studies of the microorganisms associated with fermentation led to experiments refuting the spontaneous generation of life. The study of microorganisms led to the study of disease, first in silkworms, then in farm animals (anthrax), and finally in humans (rabies).

A serendipitous discovery led to the development of modern vaccination by injecting cultures of weakened microorganisms. A forgotten batch of cholera cultures from chicken was found to be incapable of infecting other chickens, but these same chickens did not contract cholera when injected with a fresh culture. The study of rabies showed that disease could

be caused by "filterable viruses" that were so small that they could not be viewed under a microscope. It also turned out that—unlike bacteria—viruses could be grown only on organic material, not in sterile chemical solutions. Still Pasteur was so confident of the results of his experiments that he agreed, albeit with some trepidation, to try the first vaccination against rabies in 1885.

In 1857, Pasteur had returned to the Ecole Normale Supérieure in Paris, but in 1868 he was stricken by a stroke that left him semi-paralyzed. Nevertheless, he continued his scientific work until near the end of his life.

Louis Pasteur was blessed with an intuition that led him to scientific results that others could not see, but he refused to accept any idea that was not confirmed by painstaking experimentation. Pseudoscientists, especially those promoting untested health products, would be well advised to heed Pasteur's words:

> This marvelous experimental method, of which one can say, in truth, not that it is sufficient for every purpose, but that it rarely leads astray, and then only for those who do not use it well. ... The charm of our studies, the enchantment of science, is that, everywhere and always, we can give the justification of our principles and the proof of our discoveries.[17]

6 The Sociology of Science: Scientists Do It as a Group

Is reality real?

In a sense, virtual reality—the simulation of reality by computers, sensors, and displays—is more real than reality. This is because you can always step outside a simulation. If you have a question or a conjecture as to how the system works, you can always ask the computer engineers who developed the system to look at their hardware and software in order to give you a definitive answer. When it comes to science that studies the "real" universe, this luxury is denied us. Scientists cannot step outside the universe and see if their theories are correct.

Many people believe in a divine being who created the universe and whose existence transcends the physical universe. Presumably, the divine being could answer our questions about the structure of the universe, but existing religions contain no information whatsoever as to the correctness of relativity or quantum mechanics. Even if these topics appeared in religious doctrines, we would have no way of deciding among the different answers that would almost certainly be given by different religions, just as they give different answers concerning theological questions. Scientific theories would then be accepted upon faith rather than upon evidence.

Science can never claim to have absolute truth about reality, or even to prove absolutely that the universe itself exists. It is always possible, as Shakespeare wrote, that we have been set upon a stage to act out a drama:

> Life's but a walking shadow, a poor player
> That struts and frets his hour upon the stage
> And then is heard no more.
> It is a tale
> Told by an idiot, full of sound and fury,
> Signifying nothing.[1]