Preface to the Student

Human beings arrive at truth in four ways: Faith, authority, revelation, and observation. All other animals rely only upon authority, by observing adults, and observation, by, for example, tasting fruit or experiencing the changing of the seasons. Very few species other than Man, although they, too, may experience territorialism, practice genocide or wage organized war. This is perhaps a commentary on the truth-finding role of faith, authority, and revelation in our consciousness.

The Role of Rational Inquiry

As tempting as it might be, these four methods cannot be organized historically. All four have existed since man obtained consciousness and remain practiced today. Similarly, they cannot be organized culturally. Native American populations, Chinese, the Maya and Incas, African tribes, Alaskan Indians, residents of the sub-continent, Pacific island inhabitant, and other civilizations developed religions, leaders, god-figures, and rational science. When anthropologists study previously unknown tribes, they find all four methods of obtaining truth in operation. Hope and prayer, shaman and village elders, miracles, and planning for the seasons, for examples, manifest the four methods.

In Western civilization, a tradition of rational inquiry and literacy of the Greeks was displaced by the revelation-inspired ignorance of the Dark Ages. Noteworthy was the nearly universal illiteracy during that 1,000-year period, when revelation-truth was communicated through art, notably religious paintings, drawings, and stained glass. The development of advanced seaworthy ships during the Age of Exploration and the consequent encounter with other civilizations with their own religions, the availability of books after the invention of the printing press, and the courage, insight, and brilliance of those who wondered about nature led to an outbreak of intellectual freedom known as the Renaissance, literally "re-birth."

THE HUMAN INTELLECT

PRIMARY FIELDS	APPLIED FIELDS
Physics*	engineering, astronomy, geology, meteorology, oceanography
Chemistry	synthetics, botany
Biology	medicine, zoology, genetics, paleontology
Psychology	linguistics, philosophy, education, the arts
Sociology	anthropology, archaeology, architecture, economics, trades, agriculture, business, military, philanthropy, politics and law
History	religion

*in the present context, mathematics is considered as the language of physics

Leading the scientific Renaissance was the emphasis upon observation as the means of reaching truth. The observations of Tycho Brahe (1546–1601), codified by Johannes Kepler (1571–1630) into the laws which bear his name, the insistence of Galileo Galilei (1564–1642) upon the power of observation, and Sir Isaac Newton's (1643–1727) synthesis of Kepler's Laws with the Universal Law of Gravitation which he discovered occurred in rapid succession. Although Hans Lippershey (1570–1619) built the first telescope, it was Galileo's observations of the imperfective appearances of the surfaces of the Moon and Sun, the phases of Venus, and the orbiting satellites of Jupiter which displayed the intellectual value of direct observation to Europeans. In a well-studied era in the history of science, many of these scholars and their followers faced intellectual and physical hardship as they threatened the role of revelation.

As laws of nature were discovered, new mathematics was developed to allow their analysis and to provide the ability for prediction. In this way, Rene Descartes (1596–1650), Newton, and Gottfried Wilhelm Leibniz (1646–1716) developed the calculus, Newton to analyze the motions of the planets. He realized that the state of any system can be determined at any time if the rate of change of that system could be written down and an initial state provided. Following the formulation of the laws of electricity and magnetism by Michael Faraday (1791–1867), Charles-Augustin de Coulomb (1736–1806), and others, their unification by Sir James Clerk Maxwell (1831–1879), including the strange magnetic force which counter intuitively occurs at right angles to the direction of motion, required the development of vector algebra. In the twentieth century, the discovery of general relativity by Albert Einstein (1879–1955) provided an application for tensor algebra. Today, inscrutable facts about the universe such as the existence of dark energy, the incredible relative weakness of the gravitational force, and the only mildly-satisfactory Standard Model for sub-atomic particles provides the impetus for the development of string theory.

Through it all, alone among all the sciences, stands the first science, astronomy. The Renaissance pioneers of modern science were stimulated by astronomical observations. The calculus was developed to explain the motions of the planets. Galileo turned his telescope to the skies.

Uncommon for a laboratory book, I accordingly and happily include small bits on the history of astronomy. These include some perspective on figures of the Renaissance as well as on modern researchers such as Maarten Schmidt.

In this book, I try to show the unequalled power of observations in reaching truth. Study of the complete scientific method is best done in philosophy of science classes, and accordingly I do not dwell on other of its aspects, classification of observations, formulation of hypothesis, prediction, and self-correction.

Astronomy as Physics

Displaying unashamedly a personal bias, I will state that physics provides the foundation of all human inquiry, whether the construct is direct or applied. The only limitation is appreciating these connections analytically is our limited intellect. In this way, chemistry is based on physics, biology is based on chemistry, and psychology is based on biology. Sociology is mass psychology and history can be considered psychology with the added dimension of time. Engineering, astronomy, geology, meteorology, and oceanography can be considered applied physics. Similarly, synthetics and botany can be considered applied chemistry; medicine, zoology, genetics, and paleontology can be considered applied biology; linguistics, philosophy, education, and the arts can be considered applied psychology; anthropology, archaeology, architecture, economics, the trades, agriculture, business, the military, philanthropy, and politics and law can be considered applied sociology; and religion can be considered applied history. Any inability to analytically derive the direct connection to physics results from our limited intelligence. (Unlike us, Hari Seldon in Isaac Asimov's *Foundation* series had the intellect to predict history from mass psychology).

The connection of physics to astronomy is direct and the two fields have much in common. Both rely totally (except when emotions get in the way of researchers with opposing views) on the scientific method, most notably the power of observation. Both use the construct of mathematics to interpret these observations and to make predictions.

The one manner in which they differ is the role of the experiment. In physics, most of the experiments are performed in a laboratory, whether it be in a small room or a particle accelerator with a diameter measured in kilometers. In astronomy, except for those who study Moon rocks or meteoritic material, almost everything we learn results from observing the electro-magnetic radiation, whether it be light waves, radio waves, x-rays, or any other type, reaching us from celestial objects. This is, in the words of at least one esteemed astronomer, "how we know what we know" about the universe. (Because the goal of astronomy is to learn the nature of celestial objects, and because no one yet can determine the origin of a particular batch of cosmic rays, except for the solar wind particles, I do not consider the study of cosmic rays as a bona fide subject in astronomy. Others may differ with me on this issue.)

In this laboratory book, then, we will attempt to inculcate in you three things. Everything in astronomy is based on physics; indeed, that's the reason for the title of the book! Second, mathematics is our friend, specifically those mathematics in mathematical physics. Third, the study of the electro-magnetic radiation from celestial objects enables us to understand their nature.

The Experiments

First, I provide mathematical tools. These are valuable to all in our society, scientists and non-scientists. The ability to draw and understand graphs, in particular, is lacking in many who would be considered educated, but is required by educators, government employees, businessmen, as well as NASA researchers. The order of magnitude calculation, though practiced mainly by scientists, is a valuable tool.

Astronomy, except, as noted, for the study of Moon rocks, meteorites and, perhaps, cosmic rays (to repeat, the inability to detect the object of origin makes their relevance to astronomy questionable), relies on the remote observations of celestial objects by telescopes. Two laboratory exercises discuss the optics of those instruments.

With these tools in hand, I turn to subjects of the solar system. Kepler's Laws, Newton's Laws, and the Universal Law of Gravitation are presented. To give an idea of how non-modern civilizations might deal with the path of the Sun over the sky and the seasons, a semester-long project to determine the observer's geographical latitude is provided. The formation of impact craters is discussed in the context of the conservation of energy and mathematical models. The era of space exploration relies heavily on remote sensing of the surfaces and subsurfaces of planets. Diffuse reflection from the Moon and planetary surfaces, radar reflections from rotating planets and asteroids, and microwave radiation from heated planetary surfaces, with the associated physics of polarized light, the laws of reflection, the Doppler shift, heat conduction, and radiative transfer are introduced in these contexts. With an introduction to the techniques of radio astronomy having been made, we also turn our radio telescope to observe the Moon.

The observations of stars and galaxies rely upon the laws of radiation. A laboratory on blackbody radiation introduces Planck's law, Wien's displacement law, and the Stefan-Boltzmann Law. These are applied to determine the photospheric temperature and energy output of the Sun. Studying the emission lines from a gas-discharge tube introduces quantum mechanics. Finally, the knowledge of blackbody radiation and discrete radiation are combined in a study of Kirchhoff's Laws of Radiation.

Perhaps astronomers' most important tool, in addition to the pencil and the computer, Kirchhoff's laws allow direct study of the composition, velocity, density, temperature, and rotation of objects. Additional interpretation of spectra determines nearly everything else we learn about them. Indeed, these laws lead to the discovery of the very existence of barely or non-luminous objects such as cold interstellar and intergalactic clouds and black holes, and objects whose radiation is dominated by companion objects, such as extra-solar planets.

In this way, you will have encountered much of the physics behind astronomy. You will hopefully learn that the laws of physics drive phenomena governing the smallest particles to the largest clusters of galaxies, but that only observation can provide the truth lying within those objects.

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