
Light and Telescopes

Stars over the Keck Telescope dome atop Mauna Kea (© 1990 Roger Ressmeyer—Starlight)
PREVIEW

Virtually everything we know about the universe beyond the Earth is based on our interpretation of the light that we receive from celestial objects. In this chapter we will explore the nature of light and the processes by which it is emitted and absorbed. Like the laws of motion we presented previously, the principles discussed here will underlie the whole of our study of astronomy, and you should keep them in mind throughout the remainder of the course. The latter portion of the chapter describes the technology astronomers use to gather and analyze light from distant sources. The telescopes described here, both on the ground and in space, are the material monuments to our science, and they will help you to see how modern science depends on technology in order to advance.

Some of the tools for unlocking the secrets of the universe became available with the publication of Newton's *Principia* in the 1680s, but others had to wait two hundred years or more to be discovered. The laws of motion allowed astronomers to understand how the heavenly bodies move, and they were of fundamental importance in unraveling the clockwork mechanism of the solar system. To comprehend the essential nature of a distant object, however—to learn what it is made of and what its physical state is—on must understand what light is and how it is emitted and absorbed and must have tools to capture the light and analyze it. The only information we can obtain on the nature of a distant object is conveyed by the light that reaches us from it. Fortunately, an enormous amount of information is there, and astronomers have learned much about how to dig this information out.

THE ELECTROMAGNETIC SPECTRUM

One characteristic of light is that it acts like a wave (Fig. 4.1). It is possible to think of light as passing through space like ripples on a pond (although, as we will discuss shortly, the picture is actually somewhat more complicated than that). The distance from one wavecrest to the next, called the wavelength, distinguishes one color from another. Red light, for example, has a longer wavelength than blue light. It is possible to spread out the colors in order of wavelength, using a prism to obtain the traditional rainbow. Newton was the first to discover that sunlight contains all the colors, and he did so by carrying out experiments with a prism (Fig. 4.2). Whenever light is spread out by wavelength, the result is called a spectrum; that is, a spectrum is the arrangement of light from an object according to wavelength. The science of analyzing spectra is called spectroscopy and will be discussed later in this chapter.

The concept of frequency is often used as an alternative to wavelength in characterizing light waves. The frequency is the number of waves per second that pass a fixed point. It is determined by the wavelength and the speed with which the waves move. The speed of light, usually designated c, is constant, and the frequency of light with wavelength \( \lambda \) is \( f = c / \lambda \). The standard unit for measuring frequency is the hertz (Hz), one hertz being equal to one wave per second. The frequency of visible light is typically about \( 10^14 \) Hz.

![Figure 4.1 Properties of a wave. Light can be envisioned as a wave moving through space at a constant speed, usually designated c. The distance from one wavecrest to the next is the wavelength, often denoted by the Greek letter lambda, \( \lambda \). The frequency \( f \) is the number of wavecrests that pass a fixed point per second and is related to the wavelength and the speed of light by \( f = c / \lambda \).](image)

![Figure 4.2 Prism dispersing light. The rainbow of colors seen here is a spectrum. (Runk/Schoenberger, Grant Heilman Photography)](image)
Thinking Like an Economist

Every field of study has its own language and its own way of thinking. Mathematicians talk about axioms, integrals, and vector spaces. Psychologists talk about ego, id, and cognitive dissonance. Lawyers talk about venue, torts, and promissory estoppel.

Economics is no different. Supply, demand, elasticity, comparative advantage, consumer surplus, deadweight loss—these terms are part of the economist’s language. In the coming chapters, you will encounter many new terms and some familiar words that economists use in specialized ways. At first, this new language may seem needlessly arcane. But as you will see, its value lies in its ability to provide you with a new and useful way of thinking about the world in which you live.

The purpose of this book is to help you learn the economist’s way of thinking. Just as you cannot become a mathematician, psychologist, or lawyer overnight, learning to think like an economist will take some time. Yet with a combination of theory, case studies, and examples of economics in the news, this book will give you ample opportunity to develop and practice this skill.

Before delving into the substance and details of economics, it is helpful to have an overview of how economists approach the world. This chapter discusses the field’s methodology. What is distinctive about how economists confront a question? What does it mean to think like an economist?
THE ECONOMIST AS SCIENTIST

Economists try to address their subject with a scientist's objectivity. They approach the study of the economy in much the same way a physicist approaches the study of matter and a biologist approaches the study of life: They devise theories, collect data, and then analyze these data in an attempt to verify or refute their theories.

To beginners, it can seem odd to claim that economics is a science. After all, economists do not work with test tubes or telescopes. The essence of science, however, is the scientific method—the dispassionate development and testing of theories about how the world works. This method of inquiry is as applicable to studying a nation's economy as it is to studying the earth's gravity or a species' evolution. As Albert Einstein once put it, "The whole of science is nothing more than the refinement of everyday thinking."

Although Einstein's comment is as true for social sciences such as economics as it is for natural sciences such as physics, most people are not accustomed to looking at society through the eyes of a scientist. Let's discuss some of the ways in which economists apply the logic of science to examine how an economy works.

THE SCIENTIFIC METHOD: OBSERVATION, THEORY, AND MORE OBSERVATION

Isaac Newton, the famous 17th-century scientist and mathematician, allegedly became intrigued one day when he saw an apple fall from a tree. This observation motivated Newton to develop a theory of gravity that applies not only to an apple falling to the earth but to any two objects in the universe. Subsequent testing of Newton's theory has shown that it works well in many circumstances (although, as Einstein would later emphasize, not in all circumstances). Because Newton's theory has been so successful in explaining observation, it is still taught in undergraduate physics courses around the world.

This interplay between theory and observation also occurs in the field of economics. An economist might live in a country experiencing rapidly increasing prices and be moved by this observation to develop a theory of inflation. The theory might assert that high inflation arises when the government prints too much money. To test this theory, the economist could collect and analyze data on prices and money from many different countries. If growth in the quantity of money were not at all related to the rate at which prices are rising, the economist would start to doubt the validity of the theory of inflation. If money growth and inflation were strongly correlated in international data, as in fact they are, the economist would become more confident in the theory.

Although economists use theory and observation like other scientists, they face an obstacle that makes their task especially challenging: In economics, conducting experiments is often difficult and sometimes impossible. Physicists studying gravity can drop many objects in their laboratories to generate data to test their theories. By contrast, economists studying inflation are not allowed to manipulate a nation's monetary policy simply to generate useful data. Economists, like astronomers and evolutionary biologists, usually have to make do with whatever data the world happens to give them.

To find a substitute for laboratory experiments, economists pay close attention to the natural experiments offered by history. When a war in the Middle East, for instance, disrupts the flow of crude oil, or a strike keeps workers from their jobs, or a drought reduces the crop yields, economists may use these events as natural experiments. If they observe a change in the price of oil, or a rise in the wages of workers, or a fall in the crop yields, they may be able to determine whether and how the change in the oil price, or the wage, or the crop yields affected the price of goods.
The Greek Achievement

Chapter Outline
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Documents
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Aristophanes on the Shortcomings of Athenian Democracy

Scarred by time and weather, the ruins of the Athenian Acropolis stand against a vivid blue sky and overlook the trees and buildings of a modern city sprawled beneath. These ruins are striking symbols of a departed civilization whose principal center was Athens.

In the fifth century B.C. the temples and statuary of the Acropolis were gleaming and new, fresh from the hands of builders and sculptors. Five hundred years later; when Greece was a province of the Roman Empire, they still appeared so to Plutarch:

The works... are wonderful; they were quickly created and they have lasted for ages. In beauty each one appeared venerable as soon as it was finished, but in freshness and vigor it looks even now new and lately built. They bloom with an eternal freshness that seems untouched by time, as though they had been inspired by an unaging spirit of youth.

Today the Acropolis no longer appears to be "untouched by time"; yet for us no less than for Plutarch, ancient Athens and the civilization that was centered there has retained an "eternal freshness." Greece's accomplishments were to prove...
enduring. Its magnificent intellectual and artistic legacy would provide much of the cultural heritage of Western civilization, and when we look at the Greek experience as a whole—political, economic, social, religious, and cultural—we can understand the significance of Arnold Toynbee's words, "The Greeks went over the same road before us."

THE BACKGROUND: AEGEAN CIVILIZATION, 2000-1200 B.C.

Greek civilization was preceded by an advanced civilization located on the lands surrounding the Aegean Sea. This Aegean civilization, which came into full flower about 2000 B.C., and collapsed suddenly following 1200 B.C., developed through two major periods.

Early Minoan and Mycenaean Phases

The first and longer phase of Aegean civilization ended about 1450 B.C. and is called Minoan after the legendary Cretan king Minos. Crete was the center of Minoan civilization, which spread to the Aegean Islands, the coast of Asia Minor, and mainland Greece (see map, p. 40). The last period of Aegean civilization, the two-and-one-half centuries following 1450 B.C. when the center of Aegean political power and culture lay on the Greek mainland, is called Mycenaean after its most important site at Mycenae.

The Minoans

The narrow, 160-mile-long island of Crete was a stepping stone between Europe, Asia, and Africa. Stimulated by immigrants from Asia Minor and by contacts with Mesopotamia and Egypt, a brilliant civilization emerged here by 2000 B.C.

Minoan prosperity was based on large-scale trade that ranged from Sicily, Greece, and Asia Minor to Syria and Egypt. The Minoans employed the first ships capable of long voyages over the open sea. Chief exports were olive oil, wine, metalware, and magnificent pottery. This trade was the monopoly of an efficient bureaucratic government under a powerful ruler whose administrative records were written on clay tablets, first in a form of picture writing and later in a script known as Linear A, whose 87 signs represented syllables. As neither script has been deciphered, our knowledge of Minoan civilization is scanty and imprecise; most of it is derived from the material remains uncovered by archaeologists.

It was the epoch-making discoveries of the English archaeologist Sir Arthur Evans that first brought to light this civilization, whose existence had previously only been hinted at in the epics of Homer and in Greek legends such as that of the minotaur; half bull and half man, who devoured youths and maidens sent as tribute from Greece. Between 1900 and 1905 Evans unearthed the ruins of a great palace at Knossos, the dominant city in Crete after 1700 B.C. Rising at least three stories high and sprawling over nearly six acres, this "Palace of Minos," built of brick and limestone and employing unusual downward-tapering columns of wood, was a maze of royal apartments, storerooms, corridors, open courtyards, and broad stairways. Equipped with running water, the palace had a sanitation system that surpassed anything constructed in Europe until Roman times. Walls were painted with elaborate frescoes in which the Minoans appear as a happy, peaceful people with a pronounced liking for dancing, festivals, and athletic contests. Women are shown enjoying a freedom and dignity unknown elsewhere in the ancient Near East or classical Greece. They are not secluded in the home but are seen sitting with men and taking an equal part in public festivities—even as toreros in a form of bullfighting. Their dresses are very elaborate, with gay patterns and colors, pleats, puffed sleeves, and flounces. Bodices are open in front to the waist, and hair is elaborately fashioned with ringlets over the forehead and about the ears.

The most notable feature of Minoan culture was its art, spontaneous and full of rhythmic motion. Art was an essential part of everyday life and not, as in the ancient Near East, an adjunct to religion and the state. What little is known of Minoan religion also contrasts sharply with conditions in the Near East: there were no great temples, powerful priesthoods, or large cult statues of the gods. The principal deity was the Mother Goddess; her importance reflected the important
8.6 Probability

The Probability of an Event • Mutually Exclusive Events • Independent Events • The Complement of an Event

The Probability of an Event

In Section P.7, you were introduced to the concept of the probability of a simple event. Recall that any happening whose result is uncertain is called an experiment. The possible results of the experiment are outcomes, the set of all possible outcomes of an experiment is the sample space of the experiment, and any subcollection of a sample space is an event.

For instance, when a six-sided die is tossed, the sample space can be represented by the numbers from 1 through 6. For this experiment, each of the outcomes is equally likely.

To describe sample spaces in such a way that each outcome is equally likely, you must sometimes distinguish between various outcomes in ways that appear artificial. Example 1 illustrates such a situation.

**EXAMPLE 1 Finding the Sample Space**

Find the sample spaces for the following.

a. One coin is tossed.  
   b. Two coins are tossed.  
   c. Three coins are tossed.

**Solution**

a. Because the coin will land either heads up (denoted by $H$) or tails up (denoted by $T$), the sample space is $S = \{H, T\}$.  
   **Outcome = Heads or Tails**

b. Because either coin can land heads up or tails up, the possible outcomes are as follows.

   $HH$ = heads up on both coins
   $HT$ = heads up on first coin and tails up on second coin
   $TH$ = tails up on first coin and heads up on second coin
   $TT$ = tails up on both coins

Thus, the sample space is $S = \{HH, HT, TH, TT\}$. Note that this list distinguishes between the two cases $HT$ and $TH$, even though these two outcomes appear to be similar.

**Sequence matters**

<table>
<thead>
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<td>$S$</td>
<td>$HH, HT, TH, TT$</td>
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   **Sequence matters**

c. Following the notation of part (b), the sample space is

   $S = \{HHH, HHT, HTH, HTT, THH, THT, TTH, TTT\}$.  

To calculate the probability of an event, count the number of outcomes in the event and in the sample space. The number of outcomes in event $E$ is denoted by $n(E)$ and the number of outcomes in the sample space $S$ is denoted by $n(S)$. The probability that event $E$ will occur is given by $\frac{n(E)}{n(S)}$.

**The Probability of an Event**

If an event $E$ has $n(E)$ equally likely outcomes and its sample space $S$ has $n(S)$ equally likely outcomes, the probability of event $E$ is

$$P(E) = \frac{n(E)}{n(S)}.$$  

Because the number of outcomes in an event must be less than or equal to the number of outcomes in the sample space, the probability of an event must be a number between 0 and 1. That is,

$$0 \leq P(E) \leq 1.$$  

If $P(E) = 0$, event $E$ cannot occur, and $E$ is called an impossible event. If $P(E) = 1$, event $E$ must occur, and $E$ is called a certain event.

**EXAMPLE 2 Finding the Probability of an Event**

a. Two coins are tossed. What is the probability that both land heads up?

b. A card is drawn from a standard deck of playing cards. What is the probability that it is an ace?

**Solution**

a. Following the procedure in Example 1(b), let

$$E = \{HH\}$$

and

$$S = \{HH, HT, TH, TT\}.$$  

The probability of getting two heads is

$$P(E) = \frac{n(E)}{n(S)} = \frac{1}{4}.$$  

b. Because there are 52 cards in a standard deck of playing cards and there are four aces (one in each suit), the probability of drawing an ace is

$$P(E) = \frac{n(E)}{n(S)} = \frac{4}{52} = \frac{1}{13}.$$  

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**Related Real Life**

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This is a book about moral issues. What are moral issues? To answer this question, we need to consider the definition of philosophy. If the word itself is any guide, philosophy is the love of wisdom. A simple definition of wisdom, in turn, is good judgment. Philosophy then, is the love or pursuit of good judgment. Moral philosophy, or ethics, is the pursuit of good judgment about character and action—about what kind of person to be and about what to do. Ethics addresses questions about virtue and vice, good and bad, right and wrong.

Such questions, clearly, have varied answers; they are often the subject of controversy and debate. The moral issues considered in this book—abortion, euthanasia, pornography, capital punishment, affirmative action, and many others—are among the most controversial our society faces. Most of this book consists of moral arguments, in which a moral issue is considered and a particular position is supported or a particular conclusion is reached through reasoning.

How can we think moral issues through carefully and systematically? How do we develop arguments for ethical conclusions? These are questions that I attempt to answer in this introduction. I also consider an important objection to the idea of moral argument, namely, the view that different groups have different values and it is therefore impossible to argue logically about right and wrong. This position, known as relativism, is common today and poses a serious challenge to ethical thinking.

Relativism
Allan Bloom began his 1987 book *The Closing of the American Mind* with the statement, "There is one thing a professor can be absolutely certain of: almost every student entering the university believes, or says he believes, that truth is relative." This is especially so in philosophy courses and in ethics courses in particular. Ethics consists of principled reflection on questions such as How should I live? and What should I do? It takes as its central tasks criticizing, justifying, and deciding on various answers to these questions. No one, of course, likes to be criticized; no one likes to think that his or her particular answer to the question How should I live? is unjustified or just plain wrong. So it can be tempting to deflect these questions by saying that truth in ethics is relative.

But relative to what? To an individual person? To a society, a culture, or the currently popular formulation, "interpretive community"? To humanity as a whole? The last, relativism to humanity, does not challenge the traditional project of ethics at all; Aristotle characterizes ethics as the search for the good life for man. Even the second, relativism to a society or a culture, has little effect on the discussions of contemporary issues in this book. The readings debate social problems in the context of affluent, technologically advanced societies such as those of the United States, Canada, and Europe. Problems such as welfare, abortion, and world hunger might look very different from the perspective of a poor developing nation. Relativism to a society or a culture does, however, have an impact on the theoretical discussions in the classic readings in this collection, which

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generally purport to say something about what is good for human beings, not just residents of the United States, Canada, or Europe. And relativity to an individual makes ethical thinking absurd; what is good for me may differ so completely from what is good for you that ethical reflection and argument make no sense.

To be more precise, let us say that an ethical relativist believes that fundamental ethical truth—the basic truth about how one should live and what one should do—is relative to a group smaller than humanity as a whole. Something may be fundamentally right for one group but fundamentally wrong for another. A cultural relativist holds that fundamental ethical truth is relative to a culture; an individual relativist holds that it is relative to each individual person.

These definitions depend on the idea of fundamental ethical truth. Certain answers to ethical questions presuppose other answers to more basic questions. An ethical truth is fundamental if it does not depend on facts and derivate if it does. Disagreement over fundamental ethical truths is thus purely ethical; it does not stem from a factual disagreement. To say that something may be fundamentally right for one group but fundamentally wrong for another is thus to say that there may be different answers to the questions of how to live and what to do for these groups, even though the factual circumstances and the groups’ beliefs about the factual circumstances are exactly the same.

If we make no distinction between fundamental and derivative truths, individual relativism is obvious. Suppose that John has murdered someone and Mary has done no harm to anyone. Then John deserves to be punished and Mary does not. John should turn himself over to the police; Mary should not. John’s obligations differ from Mary’s because of the facts. Relativism is interesting only when it pertains to the most fundamental ethical truths, which are independent of facts. What these are, of course, is controversial. Different moral theories espouse different candidates. But it is at the level of fundamental truths—maximize good, treat others as ends, not merely as means, treat others as you would want to be treated—that the issue must be decided.

Relativism is often motivated by tolerance or openness. Since tolerance is a virtue, relativists see their own position as morally required. Bloom observes,

That it is a moral issue for students is revealed by the character of their response when challenged—a combination of belief and indignation: “Are you an absolutist?”, the only alternative they know, uttered in the same tone as “Are you a monarchist?” or “Do you really believe in witches?” This latter leads into the indignation, for someone who believes in witches might well be a witch-hunter or a Salem judge. The danger they have been taught to fear from absolutism is not error but intolerance.°

But tolerance and relativism are not the same thing. I may believe that I am right and you are wrong, while still tolerating your behavior and respecting your right to be wrong. The traditional belief in freedom of thought and freedom of speech requires just such an attitude.

Conversely, I may be a relativist, holding only that my opinion is right for me, yet show little tolerance for any deviation from my opinion. The intolerance of relativists is not only possible but common enough to have a label: political correctness. Friedrich Nietzsche predicted that the twentieth century would be a century of great wars, precisely because it would be a century of relativism. Without truth, Nietzsche understood, there is only power.

Bloom frets that his students cannot defend their opinions. But it is possible to think through issues in ethics, including ethical relativism, carefully and systematically, as mentioned earlier. This introduction provides you with some tools—the basic elements of reasoning—that will help you do this. It tells you how to recognize and evaluate arguments. The examples used are arguments for and against ethical relativism. At the end, you should not only know how to analyze an argument critically but also have greater insight into relativism.

Arguments

Arguments are bits of reasoning in language. Frequently, we think of arguments as conflicts. In that sense, this issue such action. But “argument” is a process of trying to justify

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sense, this book presents a series of arguments over issues such as abortion, euthanasia, and affirmative action. But philosophers and logicians primarily use "argument" in the sense that one argues for a conclusion. An argument starts with some assertions and tries to justify a thesis.

**Components of Arguments**

The initial assertions of an argument are its premises, the thesis that the argument tries to justify is its conclusion. Arguments consist of statements that can be true or false. Almost every sentence in this book falls into this category. Statements are declarative, in the indicative mood; they say something about the way the world is, correctly or incorrectly.

Here, for example, is a simple argument that some have advanced in favor of cultural relativism:

1. Societies differ in their fundamental ethical beliefs.
2. Ethical truth is relative to culture.

(These premises are in the order in which they are given and then gives the conclusion. The symbol \(\therefore\) means "therefore.")

How can we recognize arguments? The premises of an argument are meant to support the conclusion. We can recognize arguments, then, by recognizing when some statements are offered in support of others. We can do this most easily, in turn, if we can distinguish premises from conclusions. But how can we pick out the conclusion of an argument? In English, various words and phrases can signal the premises or the conclusion of an argument.

- **Conclusion Indicators:** therefore, thus, hence, consequently, it follows that, in conclusion, as a result, then, must, accordingly, this implies that, this entails that, we may infer that.

- **Premise Indicators:** because, as, for, since, given that, for the reason that

Beware: These words and phrases have other uses as well.

Extended or complex arguments contain other arguments. Simple arguments do not. Because extended arguments are good only if the simple arguments within them are good, it is best to break extended arguments down into their simple components and analyze them separately.

**Validity and Soundness**

To evaluate arguments, we need to ask, What distinguishes good from bad arguments? What makes a good argument good?

A good argument links its premises to its conclusion in the right way. In a ( deductively) valid argument, the truth of the premises guarantees the truth of the conclusion. If the premises are all true, then the conclusion has to be true. Or, equivalently, if the conclusion of a valid argument is false, at least one premise must also be false. Consider, for example, the argument:

1. (2) All promises ought to be kept.
2. Your promise to Joe is a promise.
3. Therefore, you ought to keep your promise to Joe.

In any circumstance in which the premises of this argument are true, the conclusion must be true as well. It is impossible to conceive of a state of affairs in which, while all promises ought to be kept, and your promise to Joe is a promise, you nevertheless should not keep your promise to Joe. If it is false that you should keep your promise to Joe, then either there are premises that shouldn't be kept, or your "promise" wasn't a real promise.

Valid arguments are only one species of good argument. Others are inductively strong (or reliable).

The truth of the premises of such an argument does not guarantee the truth of its conclusion, but it does make the truth of the conclusion probable. Consider, for example, this argument:

1. Every generous person I've ever known has also been kind.
2. All generous people are kind.

It is possible for the premise to be true while the conclusion is false. There may be generous but nasty people I've never met. So the argument is invalid.

Nevertheless, the premise lends some support to the conclusion. The argument is inductively strong: how strong depends on how many generous people I've known, among other things.

In general, good arguments not only are valid or inductively strong but also have true premises. A