The interaction concept is being used more and more widely to explain social and scientific phenomena. At conferences, strong interaction may be evident among some participants, weak interaction among others. At the ocean shore, erosion is caused by the interaction of wind and water with rock. In the laboratory, magnets interact even when they are not touching.

A dictionary provides the following definitions:

interact (verb): to act upon each other ...;

interaction (noun): action upon or influence on each other.

To say that objects interact, therefore, is to say that they have a relationship wherein they jointly produce an effect, which is the result of their action upon each other. In the examples cited above, anger may be the effect caused by strong (and irritating) interaction among the conference participants; crumbling and wearing away is the effect of the interaction of wind and water with rocks; and movement toward one another followed by sticking together is the effect of the interaction of the magnets.

3.1 Evidence of interaction

We take the point of view that influence and interaction are abstractions that we cannot observe directly. What we *can* observe are the effects or results of interaction. Congressional passage of unpopular legislation requested by the President would be an observable effect of the President's influence and therefore would be called evidence of his influence. The change in direction of motion of a struck baseball is an observable effect of its interaction with the bat and therefore can be called evidence of interaction.

You may believe that you can sometimes observe the interaction itself, as when a bat hits a baseball or a typewriter prints a letter on a piece of paper. These examples, which include physical contact and easily recognized effects, seem different from those where magnets interact without contact or where erosion is so slow that the effects are imperceptible. This apparent difference, however, is an illusion. You observe only the close proximity of bat and ball, a sound, and the change of the ball's direction of motion, all of which are so closely correlated and so familiar that you instantly interpret them as evidence of interaction between bat and ball. The interaction of bat and ball is, however, merely the relationship whereby the observable effects are brought about, and relationships are abstractions that cannot be observed directly.

Indirect evidence of interaction. An example where the evidence is very indirect was described in Section 2.2. In his analysis of the films of President Kennedy's assassination, Alvarez interpreted a blurred photograph as evidence of interaction between the photographer and a rifle being fired. No one can question the blurring in the photograph, which is directly observable. But it is clear that not everyone may agree with Alvarez's interpretation that there is a relationship between the blur and a rifle shot.

Another example of interpretation of indirect evidence for interaction is in the relationship between cigarette smoking and lung cancer. Lung cancer and cigarette smoking are separately observable, and the statistical evidence from the 1950s showed a very strong correlation, sufficient to warrant the conclusion of a pathological interaction between cigarette smoke and lung tissue (publicized in the Surgeon General's Report for 1964). There is now, in 2003, a much larger body of evidence for this interaction. Yet many smokers do not take this interpretation of the evidence seriously enough to believe that they are slowly committing suicide.

Alternate interpretations. The critical problem in interpreting evidence of interaction is that any one of several different interactions might be responsible for the same observed effect. The typed letter in the example of the typewriter and the paper does not furnish conclusive evidence as to which typewriter made the letter, a question that sometimes arises in detective stories. A direct way to overcome this weakness is to find evidence that supports one hypothesis. For instance, the paper might be beside a typewriter, the ribbon on one typewriter might match the shade of the typed letter, or a defect in the machine's type might match one that appears in the typed letter. If so, the original identification of the typewriter is supported.

An indirect way to support one hypothesis is to eliminate alternatives. By checking many typewriters and finding how poorly they match the ribbon color and type impression, the detective may be able to eliminate them from further consideration. Supporting evidence for one alternative and/or evidence against other alternatives will enable you to establish one hypothesis conclusively or may only lead you to decide that one of them is more likely than the others. A procedure for finding such evidence by means of control experiments is described in Section 3.4.

When you suspect that there might be interaction, you should make a comparison between what you observe and what you would expect to observe in the absence of interaction. If there is a difference, you can interpret your observation as evidence of interaction and seek to identify the interacting objects; if there is no difference, you conclude that there was no interaction or that you have not observed carefully enough.

3.2 Historic background

Mankind has not always interpreted observed changes or discrepancies as evidence of interaction. In ancient times, some philosophers took the view that changes were brought about by a fate or destiny that was inherent in every object. In our own day, many people ascribe specific events to supernatural or occult forces. These forms of explanation and the interaction concept we are advocating, however, *do* share a common feature: they are both attempts to explain regular patterns in nature so as to anticipate the future and possibly to influence and control future events.

Cause and effect. When you observe two happenings closely correlated in space and time, you tend to associate them as cause and effect. Such a conclusion is reinforced if the correlation of the happenings persists in a regular pattern. The person who strikes a match and observes it bursting into flame infers that the striking caused the fire. The primitive man who performs a rain dance infers that the dance causes the ensuing rain. Even the laboratory pigeon that receives a pellet of grain when it pecks a yellow card becomes conditioned to peck that card when hungry. These individuals will repeat their actions - striking the match, dancing, or pecking the card - if they wish to bring about the same consequences again. After a sufficient number of successful experiences, all three will persist in their established behavior, even though some failures accompany their future efforts.

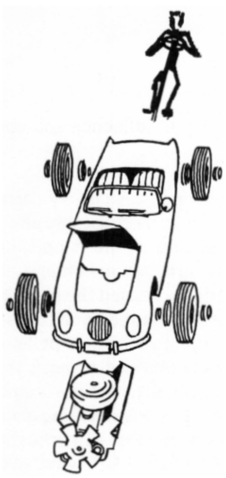
The interaction viewpoint. We may state the distinction between the modern scientific approach and other types of explanations for events in the following way: the scientist ascribes happenings to interactions among two or more objects rather than to something internal to any one object. Thus, the falling of an apple is ascribed to its gravitational interaction with the earth and not to the heaviness inherent in the apple. The slowing down of a block sliding on a table is ascribed to friction between the block and the table and not to the power or "desire" of the block to come to rest by itself. Fire is the manifestation of combustion, that is, the interaction of fuel and oxygen, and is not itself an element. The rain dance and the rain, however, cannot be put into this framework; therefore, this association is nowadays considered a superstition.

At any one time, however, science cannot provide explanations for all possible happenings. When a new phenomenon is discovered, the interacting objects responsible for it must be identified, and this may be difficult. The origin of some of the recently discovered radiation reaching the earth, for example, is yet to be found. On the other hand, we now have identified specific chemical substances in cigarette smoke that cause cancer. We are beginning to understand the specific biochemical mechanisms by which such substances cause lung cells to start the explosive multiplication that manifests itself as cancer. Research is continuing to further elucidate the details of this dangerous interaction.

3.3 Systems

The word "system" has entered our daily lives. Communication systems, computer systems, and systems analysis are discussed in newspapers and magazines and on television. In all these discussions, and in this text as well, the word "system" refers to a whole made of parts.

The systems concept is applied whenever a whole, its parts, and their inter-relationships must all be kept clearly in mind, as illustrated in the following two examples. Traffic safety studies take into account an entire driver-car system and do not confine themselves merely to the engineering of the car or the health of the driver. A physician realizes that the human heart, though a single organ, is really a complex system composed of muscles, chambers, valves, blood vessels, and so on. The system is physically or mentally separated from everything else so that the relations among the parts may be studied closely.



To simplify our terminology, we will often refer to the whole as "system" and to the parts as "objects." Thus, the car and the driver are the objects in the driver-car system, and the muscles, chambers, and so on are objects in the system called "the heart." By using the word "object" to refer to any piece of matter (animate or inanimate, solid, liquid, or gaseous), we are giving it a broader meaning than it has in everyday usage.

Sometimes one of the parts of a system is itself a system made of parts, such as the car (in the driver-car system), which has an engine, body, wheels, and so forth. In this case, we should call the part a subsystem, which is a system entirely included in another system.

In a way, everyone uses the systems concept informally, without giving it a name. At times, everyone focuses attention temporarily on parts of the environment and ignores or neglects other parts because the totality of incoming impressions at any one moment is too complex and confusing to be grasped at once. The system may have a common name, such as "atmosphere" or "solar system," or it may not, as in the example of the jet fuel and liquid oxygen that propel a rocket. The systems concept is particularly useful when the system does not have a common name, because then the group of objects under consideration acquires an individual identity and can be referred to as "the system including car and driver" or more briefly as "the driver-car system" once the parts have been designated.

"... in all the operations of art and nature, nothing is created; an equal quantity of matter exists both before and after the experiment, ... and nothing takes place beyond changes and modifications in the combinations of these elements. Upon this principle, the whole art of performing chemical experiments depends."
Antoine Lavoisier
Traite Elementaire de Chimie, *1789*

Conservation of systems. Once we have identified a system, changes may occur in the system. We must have a way to identify the system at later times in spite of the changes. A chemist uses the conservation of matter to identify systems over time. This means that no matter can be added to or removed from the matter originally included in the system. For example, when jet fuel burns, the fuel and oxygen become carbon dioxide and water. Therefore, the chemist thinks of the carbon dioxide and water as being the same system as the jet fuel and oxygen, even though the chemical composition and temperature have changed.

The psychotherapist and the economist do not use the same criteria as the chemist for following the identity of a system over time. The psychotherapist focuses his attention on a particular individual with a personality, intellectual aptitudes, and emotions. A therapist, therefore, selects this individual as a system that is influenced by its interaction with other individuals and by its internal development. The person as a system retains its identity even though it exchanges matter with its environment (breathing, food consumption, waste elimination). For the economist, all the production, marketing, and consuming units in a certain region constitute an economic system that retains its identity even though persons may immigrate or emigrate and new materials and products may be shipped in or out.

The physicist studying macro-domain phenomena finds the matter-conserving system most useful. This is, therefore, the sense in which we will use the systems concept throughout this text. In the micro domain, however, the concepts of matter and energy have acquired new meanings during the last few decades, and, if you study physics further, you will learn how to expand and modify these criteria for defining systems.

Place two identical pieces of clean writing paper in front of you. Pick up one piece and call it System P.

(1) Wrinkle the paper in your hand into a ball. Is what you now hold in your hand System P?

(2) Is the paper lying on the table System P?

(3) Tear the wrinkled paper in half, and hold both pieces. Is what you now hold in your hand System P?

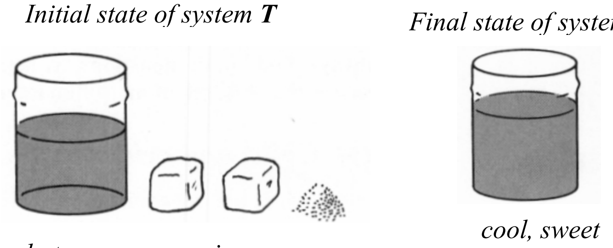
(4) Put down one of the two torn pieces. Is what you now hold in your hand System P?

You can apply conservation of matter to the selection of systems in two ways. By watching closely, you can determine whether you see the same system before and after an event. For instance, when a bottle of ginger ale is opened, some of the carbon dioxide gas escapes rapidly. The contents of the sealed bottle (we may call it System A), therefore, are not the same system as the contents of the opened bottle, which may be called System B. The escaping bubbles are evidence of the loss of material from the bottle.

In the second kind of application, you seek to keep track of the system even though its parts move from one location to another. Thus, after the bottle is opened, System A consists of System B plus the escaped gas; the latter, however, is now mixed with the room air and can be conveniently separated from the room air only in your mind. For this reason we stated at the beginning of this section that a system of objects need only be separated mentally from everything else; sometimes the physical separation is difficult or impossible to achieve, but that is immaterial for purposes of considering a system.

State of a system. To encompass the continuity of the matter in the system as well as the changes in form, it is valuable to distinguish the identity of the system from the state of the system. The identity refers to the material ingredients, while the state refers to the form or condition of all the material ingredients (Fig. 3.l). . Variable factors, such as the distance between objects in the system, its volume, its temperature, and the speeds of moving objects, are used to describe the state. In

Figure 3.1 Change in the state of a system.



Chapter 4 we will relate matter and energy, which are of central concern to the physical scientist, to changes in the state of a system. There we will describe the ways in which a system may store energy and how energy may be transferred as changes occur in the state of a system. From an understanding of energy storage and transfer has come the extensive utilization of energy that is at the base of modern technology and current civilization.

Investigations of interacting objects. In their research work, physicists study systems of interacting objects in order to classify or measure as many properties of the interactions as they can. They try to determine which objects are capable of interacting in certain ways, and which are not (e.g., magnetic versus nonmagnetic materials). They try to determine the conditions under which interaction is possible (a very hot wire emits visible light but a cold wire does not). They try to determine the strength of interaction and how it is related to the condition and spatial arrangement of the objects (a spaceship close to the earth interacts more strongly with the earth than does one that is far away from the earth). Physicists try to explain all physical phenomena in terms of systems of interacting objects or interacting subsystems.

Working models for systems and the structure of matter. There are some happenings, however, such as the contraction of a stretched rubber band that involve only a single object and appear to have no external causes. In such cases, the scientist makes a working model in which the object is made of discrete parts. A working model for the rubber band is made of parts called "rubber molecules." The properties of the entire system are then ascribed to the motion and the interaction of the parts. Some models are very successful in accounting for the observed behavior of the system and even suggest new possibilities that had not been known but that are eventually confirmed. Such a model may become generally accepted as reality: for instance, everyone now agrees that rubber bands are systems made of rubber molecules. Also, further model building may represent the rubber molecules as subsystems composed of parts called "atoms" and explain the behavior of the molecules in terms of the motion and interaction of the atoms.

This kind of model building is called the search for the structure of matter - how ordinary matter in the macro domain is composed of interacting parts, and these parts in turn are composed of interacting parts, and so on into the micro domain. One of the frontiers of science is the search for ultimate constituents, if such exist. Since we will always find more questions to ask, it is unlikely that we will ever accept the concept of an "ultimate constituent."

3.4 Collecting evidence of interaction

Interactions are recognized by their effects, that is, by the difference between what is actually observed and what would have been observed in the absence of interaction. Such a difference is evidence of interaction. The systems concept is of great value here because it enables you to designate and set apart (at least mentally) the objects that are being compared as you look for a difference. One approach is to compare a system before an event (in its so-called initial state) with the same system after an event (in its so-called final state). For example, you compare a section of bare skin on the morning and the evening of a day at the beach (Fig. 3.2). The section of skin is the system. In this experiment you assume based on your experience that the skin color would not have changed in the absence of interaction. The observed change in skin color is therefore evidence of interaction with the sun.

As another example, take some sugar and let it dissolve in water in a glass beaker to form a solution (Fig 3.1). At the beginning of the experiment, the water-sugar system consists of dry crystals and colorless, tasteless water. At the end, there are no crystals and the liquid tastes sweet. The change in the state of this system is evidence of interaction between sugar and water.

Control experiment. Consider now an experiment in which you put yeast into a sugar solution in a glass and let this system stand in a warm place for several days. You will observe bubbles, an odor, and a new taste - that of ethyl alcohol. These changes can be interpreted as evidence of interaction within the water-sugar-yeast system. Can you narrow down the interacting objects more precisely or are all three parts necessary?

For comparison, suppose you can conduct experiments in which one ingredient is omitted. You dissolve sugar in water without yeast, you dissolve yeast in water without sugar, and you mix sugar and yeast. Each of these is called a control experiment; from their outcomes, you can answer the question above. By designing other control

Figure 3.2 The skin shows evidence of interaction with the sun only where it was exposed to sunlight. The exposed skin can be compared to the unexposed areas.

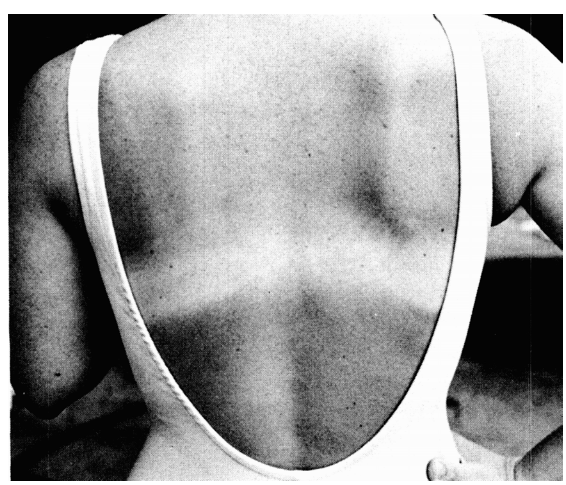


Figure 3.3 When you try to determine which electric circuit breaker supplies power to a particular light fixture, you turn on the switch of the fixture and then turn off the circuit breakers one at a time. In one of these "experiments" the bulb darkens, in the others it does not. Each turning off serves as a control experiment to be compared to the situation in which all circuits are turned on.

"It frequently happens, that in the ordinary affairs and occupations of life, opportunities present themselves of contemplating some of the most curious operations of Nature . . . I have frequently had occasion to make this observation; and am persuaded, that a habit of keeping the eyes open to everything that is going on in the ordinary . . . business of life has oftener led, as it were by accident . . . to useful doubts and sensible schemes for investigation and improvement, than all the most intense meditations of philosophers in the houses expressly set apart for study."
Benjamin Thompson, Count Rumford
Philosophical Transactions, 1798

experiments, you can try to determine whether the glass container was necessary, and whether the temperature of the environment made any difference.

By carrying out control experiments, you try to identify those objects in the system that interact and those whose presence is only incidental (Fig. 3.3).

Inertia. One other important concept in the gathering of evidence of interaction is the concept of inertia. Inertia is the property of objects or systems to continue as they are in the absence of interaction, and to show a gradually increasing change with the elapse of time in the presence of interaction. For example, you expected the pale skin on the girl's back (Fig. 3.2) to remain pale as long as it was not exposed to the sun. You expect a rocket to remain on the launching pad unless it is fired. You expect sugar crystals to retain their appearance if they are not heated, brought into contact with water, or subjected to other interactions. You expect an ice cube to take some time to melt even when it is put into a hot oven.

Your everyday experience has taught you a great deal about inertia of the objects and systems in your environment. When you compare the final state with the initial state of a system and interpret a difference as evidence of interaction, you are really using your commonsense background regarding the inertia of the system. You must be careful, however, because occasionally your commonsense background can be misleading.

"... we may remark that any velocity once imparted to a moving body will be rigidly maintained as long as the external causes of acceleration or retardation are removed . . ."
Galileo Galilei
Dialogues Concerning Two New Sciences, 1638

Inertia of motion. The motion of bodies also exhibits inertia. Curiously, motion is one of the most difficult subjects to treat scientifically because of commonsense experience. When you see a block gliding slowly on an air track (Fig. 3.4), you almost think it must contain a motor because you expect such slowly moving objects to come to rest after a very short time. In fact, the block is only exhibiting its inertia of motion because the frictional interaction with the supporting surface is very small. You must, therefore, extend your concept of inertia to cover objects in motion (such as the block), which tend to remain in motion and only gradually slow down if subject to a frictional interaction. You must also extend it to objects at rest (such as the rocket), which tend to remain at rest and only gradually acquire speed if subject to an interaction. Change in speed from one value to another - where the state of rest is considered to have "zero" speed - is therefore evidence of interaction. Galileo already identified inertia of motion even though he did not give it a name. Isaac Newton framed a theory for moving bodies in which he related their changes in speed and direction of motion to their interactions. The "laws of motion," as Newton's theory is called, will be described in Chapter 14.

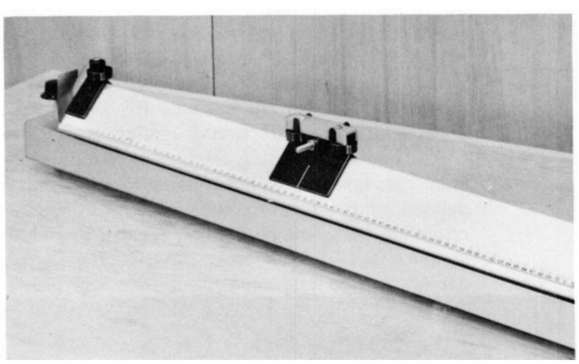
OPERATIONAL DEFINITION
Inertial mass is measured by the number of standard units of mass required to give the same rate of oscillation of the inertial balance.

A key concept in the laws of motion is that of the *inertial mass*. This is an extension of Galileo's idea that, in the absence of external influences, objects maintain their state of motion, whether at rest or moving; it is useful to have a numerical quantity which measures the extent to which an object does this: "inertial mass" is the name for this quantity. Speaking roughly, inertial mass is the degree to which a body tends to maintain its state of motion. More specifically, an object with a large inertial mass takes longer to speed up (or slow down) than an object with small inertial mass. It is important to keep in mind the *difference* between *inertial* mass and *gravitational* mass. The latter (Section 1.5) is connected with the downward pull of gravity (the weight) and can be measured with an equal-arm balance. In contrast, inertial mass can be defined and measured with a device called the *inertial balance* (Fig. 3.5) to compare two objects or to compare an object of unknown inertial mass with standard units of inertial mass.

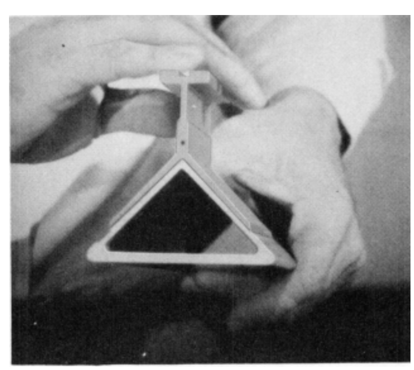
The inertial balance operates *horizontally*, thus eliminating the effects of gravity. The body attached to the end of the steel strip is repeatedly speeded up and slowed down by the oscillation of the strip. The inertia of the body, therefore, strongly influences the rate

Figure 3.4 An air track (below).
(a, below left) Small holes in the track emit tiny jets of air. When a close fitting metal piece passes over an opening, the air is trapped and forms a thin film over which the metal piece can slide with very little friction.
(b, below right) The closeness of fit can be seen in this end view.

(a)



(b)



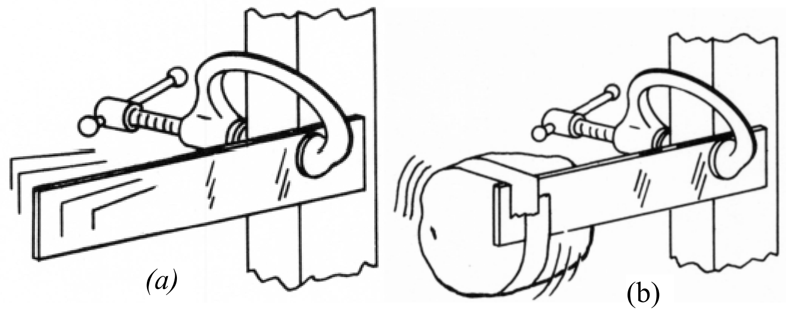


Figure 3.5 The inertial balance.
(a) The inertial balance consists of an elastic steel strip, which oscillates back and forth after the free end is pulled to the side and released.
(b) When objects are attached to the end of the strip, the oscillations take place more slowly. The inertial mass of a stone is equal to the number of standard objects required to give the same count of oscillations per minute. To measure the inertial mass of the stone, it is attached to the end of the steel strip and set into oscillation. The number of oscillations in 1 minute is counted. Then the stone is taken off, a number of standard objects are attached, and their number adjusted until the count of oscillations is equal to the count obtained with the stone.

of oscillation of the strip: large inertia (resistance to change of speed) means slow oscillations, small inertia means rapid oscillations.

The generally accepted standard unit of inertial mass is the kilogram, represented by the same platinum-iridium cylinder as the unit of gravitational mass. Even though inertial and gravitational masses are measured in the same units, they are different concepts and have different operational definitions. Inertial and gravitational mass are both important for understanding motion, particularly bodies falling under the influence of gravity. We will focus on this in Chapter 14.

FORMAL DEFINITION Momentum is the product of inertial mass multiplied by instantaneous speed.

The unit of momentum does not have a special name; it is a composite unit, kilogram-meters per second (kg m/sec) that combines mass and speed.

Equation 3.1

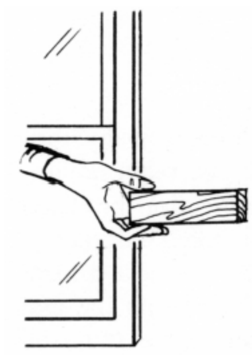
momentum $= \mathcal{M}$
speed $= v$
inertial mass $= M_I$

$$\mathcal{M} = M_I \, v$$

A second important concept in the laws of motion is the *momentum* of a moving body. The word is commonly applied to a moving object that is difficult to stop. A heavy trailer truck rolling down a long hill may, for instance, acquire so much momentum that it cannot be brought to a stop at an intersection at the bottom. By contrast, a bicycle coasting down the same hill at the same speed has much less momentum because it is less massive than the truck.

The physical concept of *momentum* is defined formally as the product of the inertial mass multiplied by the speed of the moving object (Eq. 3.1). This concept was used by Newton to formulate the laws of motion (Chapter 14), and it plays an important role in the modern models for atoms (Sections 8.3, 8.4, and 8.5). We will elaborate on the momentum concept in Chapter 13, where we will describe how it depends upon the direction of motion as well as on the speed.

If we want to use changes of motion as evidence of interaction, we must be careful because, as we have pointed out in Chapter 2, motion must be defined relative to a reference frame. An object moving relative to one reference frame may be at rest relative to another. Evidence of interaction obtained from observation of moving objects, therefore, will depend on the reference frame. We will ordinarily use a reference frame attached to a massive body such as the earth (for terrestrial phenomena) or the sun (for the solar system).



Combined interaction. A block held in your hand does not show evidence of interaction (i.e., it remains at rest), yet it is clearly subject to interaction with the hand and with the earth. This is an example of what we must describe as two interactions combining in such a way that they compensate for one another and give the net effect of no interaction. Situations such as this raise the question of the strength of interaction; how can you compare two interactions to determine whether they can compensate exactly or not, other than to observe their combined effect on the body? We will take up this question in Chapter 11.

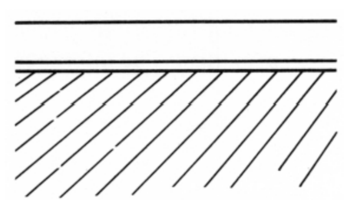
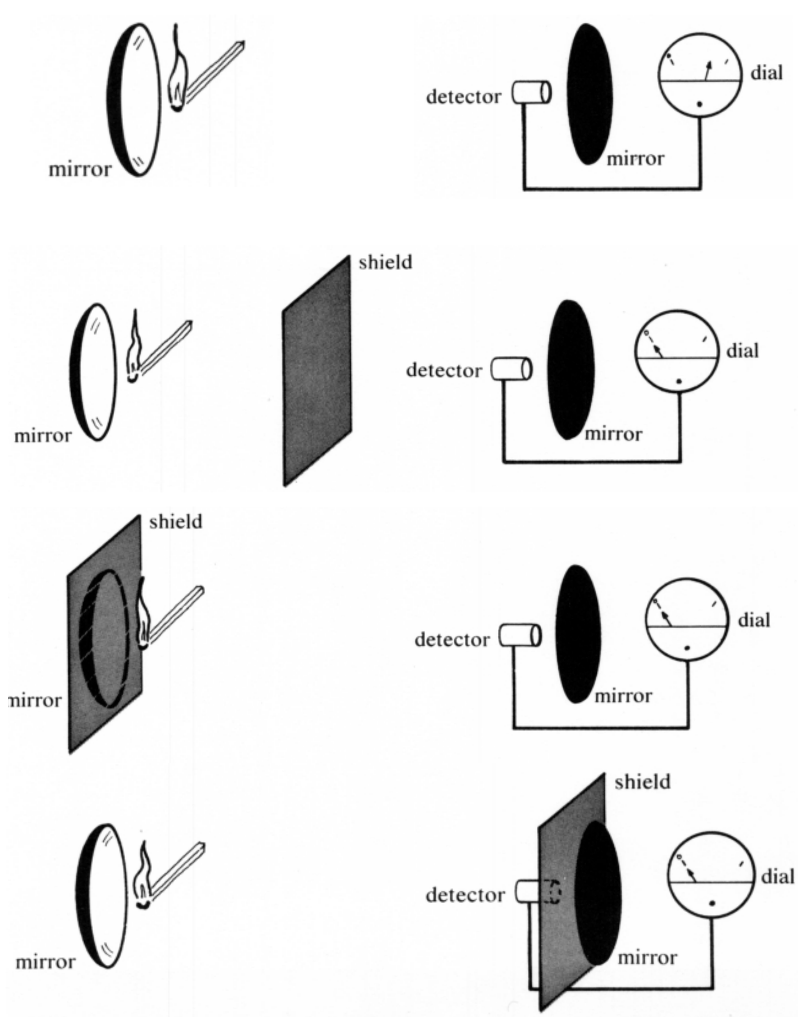
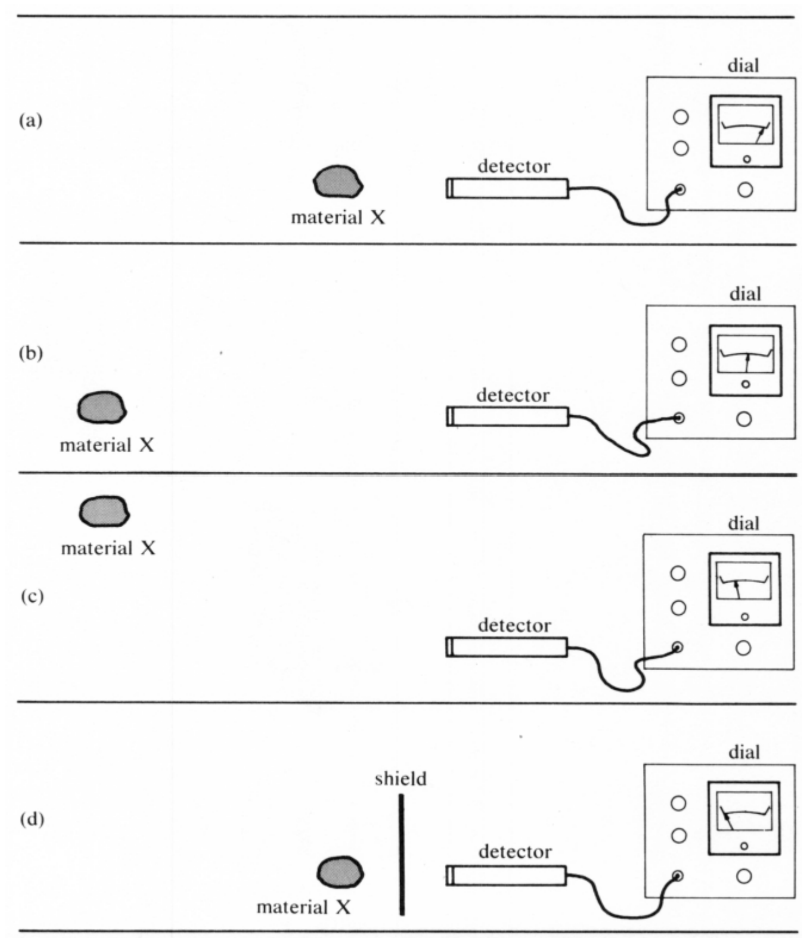


Figure 3.6 Four steps in the investigation of the interaction of a match flame with a detector show the effects of a shield placed in various locations.



Radiation. A situation that contains a different element of mystery is illustrated in Fig. 3.6. Two mirrors are facing each other at a separation of several meters. There is no mechanical connection between them. At a central point near one mirror is a device called a detector, which is connected to a dial. If a lighted match is placed at a central point in front of the opposite mirror, you see a deflection on the dial (Fig. 3.6a). After a little experimentation, you recognize that the placement of the match and the dial deflection are definitely correlated. This is the evidence of interaction between the match and the detector. If, now, the match is held in position and a cardboard shield is placed in various positions in the apparatus, the deflection falls to zero [Figs. 3.6 (b), (c), and (d)]. Without anyone touching any of the visible objects used for the experiment, an effect was produced. The inference is that something

Figure 3.7 Four steps in an investigation of material X show evidence of interaction between the material and the detector.



was passing from the match to the detector by way of the mirrors, and that the shield somehow blocked or interrupted this passage.

We, therefore, construct a working model that is just like the experimental system but includes in addition an "object" that passes from the match to the first mirror, the second mirror, and the detector. The scientist calls this "model object" radiation. In terms of this model, he can describe the effect of the shield on the dial reading as evidence of interaction between the shield and the radiation, he can describe the path of the radiation, he can describe the match as a radiation source, and he can describe the detector as a radiation detector.

Another experiment, with a rocklike material X and a detector with a dial, is illustrated in Fig. 3.7. From the evidence you may conclude that material X is not an ordinary inert rock but is a source of radiation, and you make a working model that includes an "object," again called radiation, that passes between material X and the detector. After this discovery, you can study the spatial distribution of the radiation by holding the detector in various directions and at various distances from the rock, you can study the interaction of the radiation with various shields (cardboard, glass, iron, and aluminum) placed to intercept it, and so on. From this kind of investigation you become more familiar with the radiation from material X and may, eventually, think of it as a real object and not only as part of a model.

The discovery of evidence of interaction is a challenge to identify the interacting objects and to learn more about the interaction: the conditions under which it occurs, the kind of objects that participate, the strength and speed with which the evidence appears, and so on. It can be the beginning of a scientific investigation.

3.5 Interaction-at-a-distance

Consider now a common feature of the two experiments with radiation. In both cases, you observed evidence of interaction between objects that were not in physical contact. We speak of this condition as *interaction-at-a-distance* because of the distance separating the interacting objects. The idea that objects interact without touching seems to contradict our intuition based on physical experience and the sensations of our bodies; therefore, we construct working models that include radiation to make interaction possible between the two objects. The shields intercept the radiation and show the effect of its presence and absence; this confirms the usefulness of our working models.

An experiment that significantly resembles the radiation experiments can be carried out with the system shown in Fig. 3.8. A spring is supported at the ends by rigid rods. If a ruler strikes the spring at point A, you see a disturbance in the spring, which is evidence of interaction, and then movement of the flag at B, another piece of evidence of interaction. The first movement is evidence of interaction between the ruler and the spring. The second is evidence of interaction of the spring with the flag.

The experiment with the spring and the flag becomes another example of interaction-at-a-distance, however, if you choose to focus

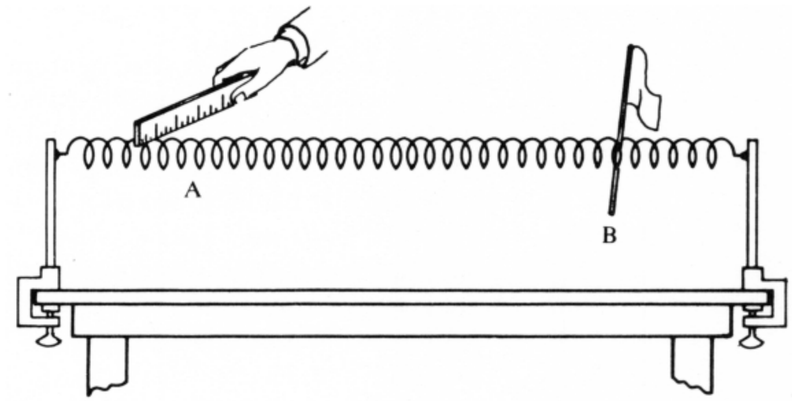


Figure 3.8 The ruler interacts with the flag by way of the long spring. Is this an example of interaction-at-a-distance?

on the system including only the ruler and the small flag. The motion of the flag correlated with the motion of the ruler is evidence of interaction-at-a-distance between these two objects. Of course, in this experiment you can see the spring and a disturbance traveling from the ruler along the spring to the flag. You do not need to construct a working model with a "model object" to make the interaction possible. You can, therefore, use the disturbance along the spring as an analogue model to help you visualize the radiation traveling from the match or material X to the detectors in the two other experiments.

The field model. Familiar examples of interaction-at-a-distance are furnished by a block falling toward the earth when it is not supported, by a compass needle that orients itself toward a nearby magnet, and by hair that, after brushing on a dry day, extends toward the brush. The intermediaries of interaction-at-a-distance in all these examples are called *fields*, with special names, such as *gravitational field* for the block-earth interaction, *magnetic field* for the compass needle-magnet interaction, and *electric field* for the brush-hair interaction. We may call this approach the *field model* for interaction-at-a-distance.

Radiation and fields. Do radiation and fields really exist, or are they merely "theoretical objects" in a working model? As we explained in Section 1.3, the answer to this question depends on how familiar you are with radiation and fields. Since radiation carries energy from a source to a detector, while the field does not accomplish anything so concrete, radiation may seem more real to you than fields. Sunlight, the radiation from the sun to green plants or to the unwary bather, is so well known and accepted that it has had a name for much longer than has interaction-at-a-distance. Nevertheless, as you become more familiar with the gravitational, magnetic, and electric fields, they also may become more real to you.

"The physicist ... accumulates experiences and fits and strings them together by artificial experiments ... but we must meet the bold claim that this is nature with ... a good-humored smile and some measure of doubt."
Goethe
Contemplations of Nature

For the scientist, both radiation and fields are quite real. In fact, the two have become closely related through the field theory of radiation, in which the fields we have mentioned are used to explain the production, propagation, and absorption of radiation. More on this subject is included in Chapter 7.

Gravitational field. Two fields, the gravitational and the magnetic, are particularly familiar parts of our environment. At the surface of the earth the gravitational field is responsible for the falling of objects and for our own sense of up and down. The plumb line (Section 1.4) and the equal-arm balance (Section 1.5) function because of the gravitational interaction between the plumb bob or the weights and the earth. We, therefore, use a plumb line to define the direction of the gravitational field at any location. Because the earth is a sphere, the direction of the gravitational field varies from place to place as seen by an observer at some distance from the earth (Fig. 3.9). More about the gravitational field will be described in Chapter 11.

OPERATIONAL DEFINITION
The direction of the gravitational field is the direction of a plumb line hanging freely and at rest.

Magnetic field. The magnetic field is explored conveniently with the aid of a magnetic compass, which consists of a small, magnetized needle or pointer that is free to rotate on a pivot (Fig. 3.10). When the compass is placed near a magnet, the needle swings back and forth,

Figure 3.9 (to right) The gravitational field near the earth is directed as indicated by plumb lines. The field appears to converge on the center of the earth

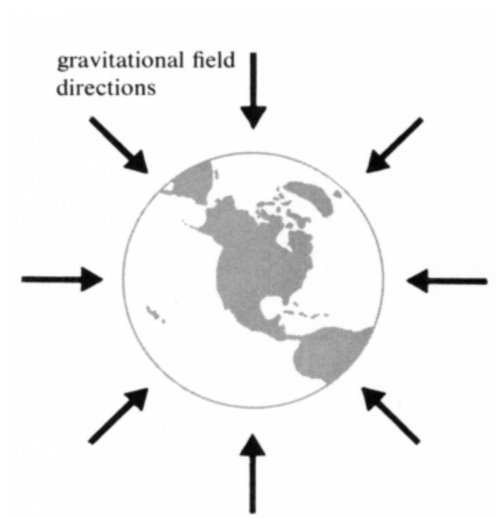
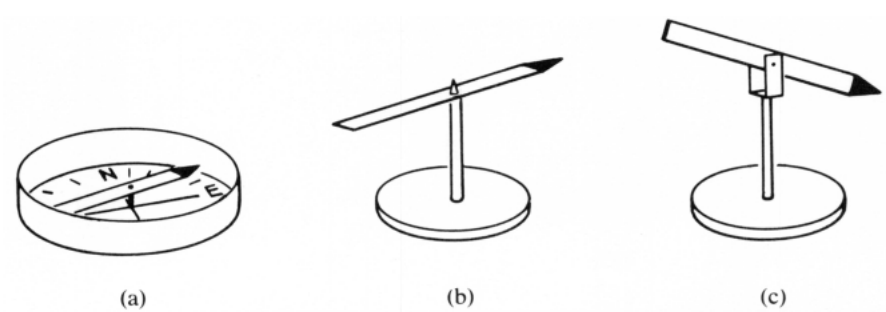


Figure 3.10 Examples of magnetic compasses. (below)
(a) The compass needle is often enclosed in a case for better protection.
(b) The pivot may permit the needle to rotate in a horizontal plane.
(c) The pivot may permit the needle to rotate in a vertical plane.



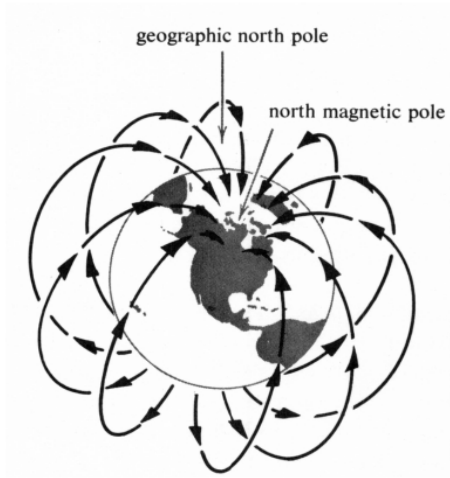


Figure 3.11 The magnetic field of the earth, represented by the arrows, lies close to the geographic north-south direction, but does not coincide with it. In the magnetic dipole model for the earth, the two magnetic poles lie near the center of the earth on a line through northern Canada and the part of Antarctica nearest Australia.

OPERATIONAL DEFINITION
The direction of the magnetic field is the direction of a compass needle that is free to rotate and has come to rest.

and finally comes to rest in a certain direction. Because of its interaction with other magnets, the compass needle functions as detector of a magnetic field at the point in space where the compass is located. It is most commonly used to identify the direction of the magnetic field at the surface of the earth, which lies close to the geographic north-south direction (Fig. 3.11). Since the compass needle has two ends, we must decide which end indicates the direction of the magnetic field. The accepted direction of the magnetic field is that of the geographic north-seeking end of the needle (henceforth called the "direction of the needle"), as shown by the arrows in Fig. 3.11**.**

Figure 3.12 The arrows represent the compass needles that indicate the magnetic field near the bar magnet.

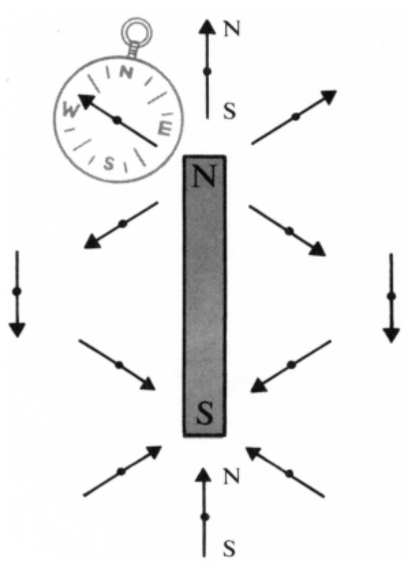
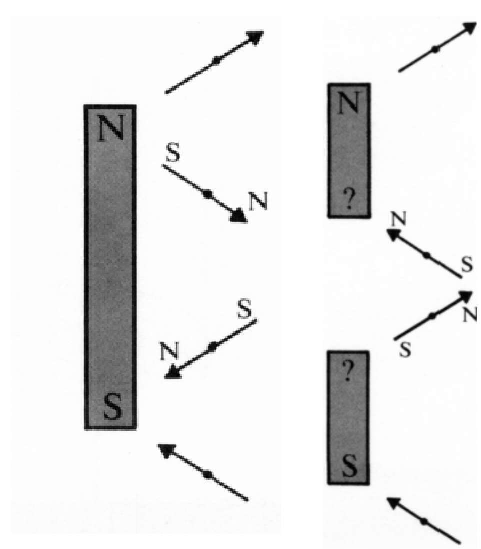


Figure 3.13 A bar magnet is cut in half in an effort to separate the north pole from the south pole. Arrows represent compass needles. Each broken part still exhibits two poles, the original pole and a new one of the opposite kind.



William Gilbert (1544-1603), an Elizabethan physician and scientist, wrote the first modern treatise on magnetism, De Magnete*. Gilbert worked with natural magnets (lodestones). In one chapter of this work, Gilbert introduced the term electric (from the Greek elektron for amber).*

Strength of the magnetic field. When you place a compass near a magnet, you notice that the needle swings back and forth rather slowly if it is far from the magnet and quite rapidly if it is close to the magnet. You can use this observation as a rough measure of interaction strength or magnetic field strength: rapid oscillations are associated with a strong field, slow oscillations with a weak field. You thereby discover that the magnetic field surrounding a magnet has a strength that differs from point to point; the field strength at any one point depends on the position of that point relative to the magnet.

Magnetic pole model. When you explore the magnetic field near a bar magnet, you find that there are two regions or places near the ends of the magnet where the magnetic field appears to originate. This common observation has led to the magnetic pole model for magnets as described in 1600 by William Gilbert (quoted to left). In this model, a magnetic pole is a region where the magnetic field appears to originate. The magnetic field is directed away from north poles and toward south poles according to the accepted convention (Fig. 3.12). All magnets have at least one north pole and one south pole. Opposite poles of two magnets attract one another, and like poles repel. If you apply these findings to the compass needle itself, you conclude that the north-seeking end of the needle contains a north pole (it is attracted to a magnetic south pole, Fig. 3.12).

"...thus do we find two natural poles of excelling importance even in our terrestrial globe . . . In like manner the lodestone has from nature its two poles, a northern and a southern . . . whether its shape is due to design or to chance . . . whether it be rough, broken-off, or unpolished: the lodestone ever has and ever shows its poles."
William Gilbert
De Magnete, 1600

An obvious question now suggests itself: can a magnetic pole be isolated? So far, physicists have failed in all their attempts to isolate magnetic poles (Fig. 3.13), in that they have not been able to narrow down the regions inside magnets where the magnetic field originates. They have found instead that the magnetic field appears to continue along lines that have no beginning or end but loop back upon themselves (Fig. 3.14). Thus, magnetic poles appear to be useful in a working model for magnets when the magnetic field outside magnets is described, but they fail to account for the field inside magnets.

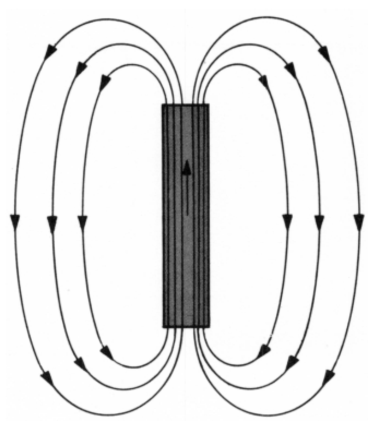


Figure 3.14 So-called magnetic field lines indicate the direction of the magnetic field. Lines inside the magnet close the loop made by the lines outside the magnet.

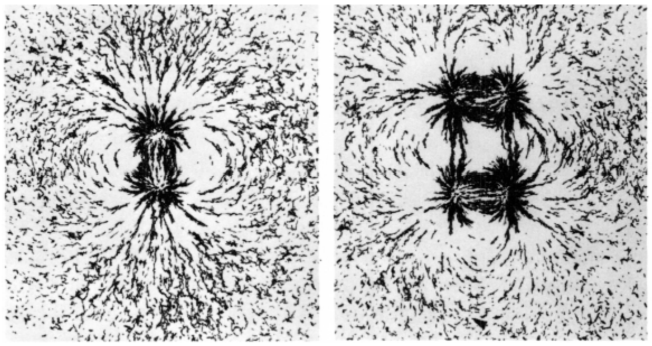


Figure 3.15 Iron filings were sprinkled over a piece of paper that concealed one or two bar magnets.

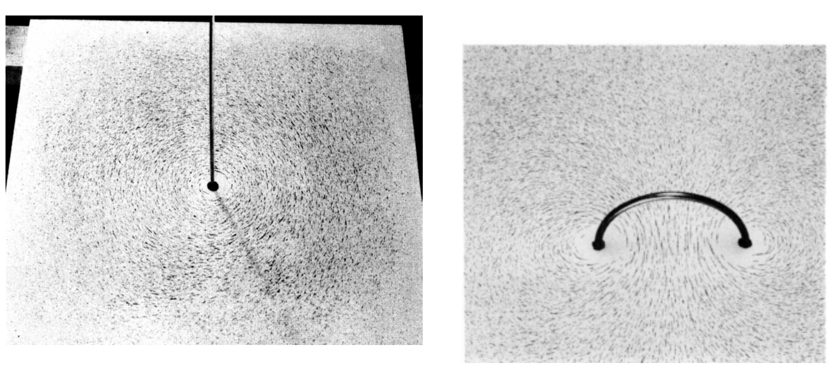
Hans Christian Oersted (1777-1851) inherited his experimental acumen from his father, an apothecary. His famous discovery in 1819 of the magnetic field accompanying an electric current took place as he was preparing for a lecture demonstration for his students. Until that time, electricity and magnetism were considered unrelated. Thus Oersted's discovery initiated intensive study of the relationships between electricity and magnetism, and these two separate disciplines gradually merged into the branch of physics known as electromagnetism.

Display of the magnetic field. Another technique for exploring a magnetic field is to sprinkle iron filings in it (Fig. 3.15). The filings become small magnets and, like the compass needle, tend to arrange themselves along the direction of the magnetic field. They produce a more visual picture of the magnetic field. This method is less sensitive than the compass, because the filings are not so free to pivot.

Electromagnetism. Not quite 150 years ago, Hans Christian Oersted, while preparing for a lecture to his students, accidentally found evidence of interaction between a compass needle and a metal wire connected to a battery. Such a wire carries an electric current (see Chapter 12). One of the most startling properties of the interaction was the tendency of the compass to orient itself at right angles to the wire carrying the electric current. Oersted's discovery is the basis of the electromagnet, a magnet consisting of a current-carrying coil of wire that creates a magnetic field. The distributions of iron filings near current-carrying wires are shown in Fig. 3.16.

Electric field. Somewhat less familiar than gravitational or magnetic fields is the electric field, which is the intermediary in the interaction of a hairbrush and the brushed hair. Electric fields also are intermediaries

Figure 3.16 Iron filings near current-carrying wires clearly show the closed loops of the magnetic field lines.



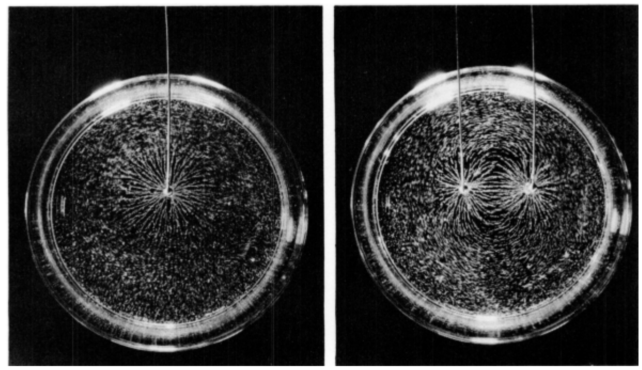


Figure 3.17 Grass seeds suspended in a viscous liquid indicate the direction of the electric field near charged objects.

"... for men still continue in ignorance, and deem that inclination of bodies to amber to be an attraction, and comparable to the magnetic coition ... Nor is this a rare property possessed by one object or two, but evidently belongs to a multitude of objects..."
William Gilbert
De Magnete, 1600

Benjamin Franklin (1706-1790) was born in Boston, Massachusetts. His father was an impoverished candle maker. Ben was apprenticed to an older brother in the printing trade. When his apprenticeship was terminated, he left for Philadelphia where he supported himself as a printer and eventually earned the fortune that freed him for public service. His political career as one of the "founding fathers' of democracy is celebrated, but it is less widely known that he was also one of the foremost scientists of his time. Franklin proposed the one-fluid theory of electricity, and he introduced the terms "positive electricity" and "negative electricity."

in the interaction of thunderclouds that lead to lightning, the interaction of phonograph records with dust, and the interaction of wool skirts with nylon stockings. Objects that are capable of this kind of interaction are called electrically charged.

Electrically charged objects. Objects may be charged electrically by rubbing. Many modern plastic materials, especially vinyl (phonograph records), acetate sheets, and spun plastics (nylon and other man-made fabrics) can be charged very easily. Electric fields originate in electrically charged objects and are intermediaries in their interaction with one another.

Display of the electric field. Individual grass seeds, which are long and slender in shape, like iron filings, orient themselves when they are placed near charged objects (Fig. 3.17). Their ends point toward the charged objects. The patterns formed by the seeds are very similar to the iron filing patterns in a magnetic field. Using the more familiar magnetic field as an analogue model for the electric field, we define the direction of the electric field to be the direction of the grass seeds.

Early experiments with electrically charged objects. Benjamin Franklin and earlier workers conducted many experiments with electrically charged objects. Gilbert had already found that almost all materials would interact with charged objects. One important puzzle was the ability of charged objects to attract some charged objects (light seeds, dry leaves, etc.) but to repel certain others. It was found, for instance, that two rods of ebonite (a form of black hard rubber used for combs and buttons) rubbed with fur repelled one another. The same was true of two glass rods rubbed with silk. But the glass and ebonite rods attracted one another (Fig. 3.18). Since a glass rod interacted differently with a second glass rod from the way it interacted with an ebonite rod, it followed that glass and ebonite must have been charged differently.

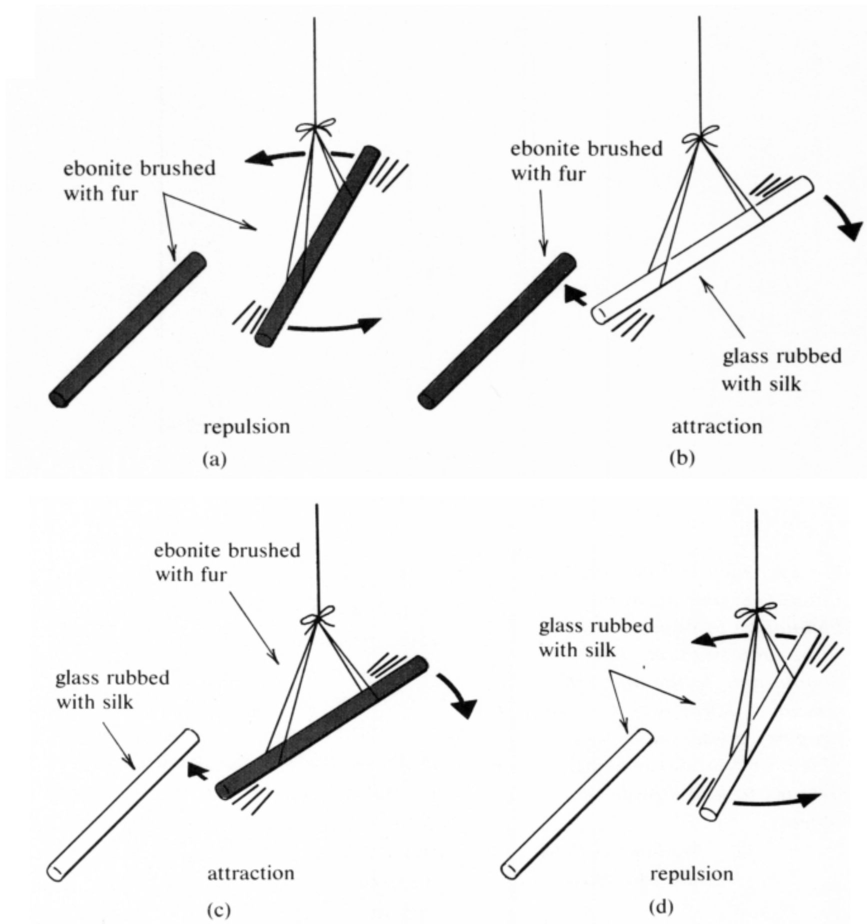


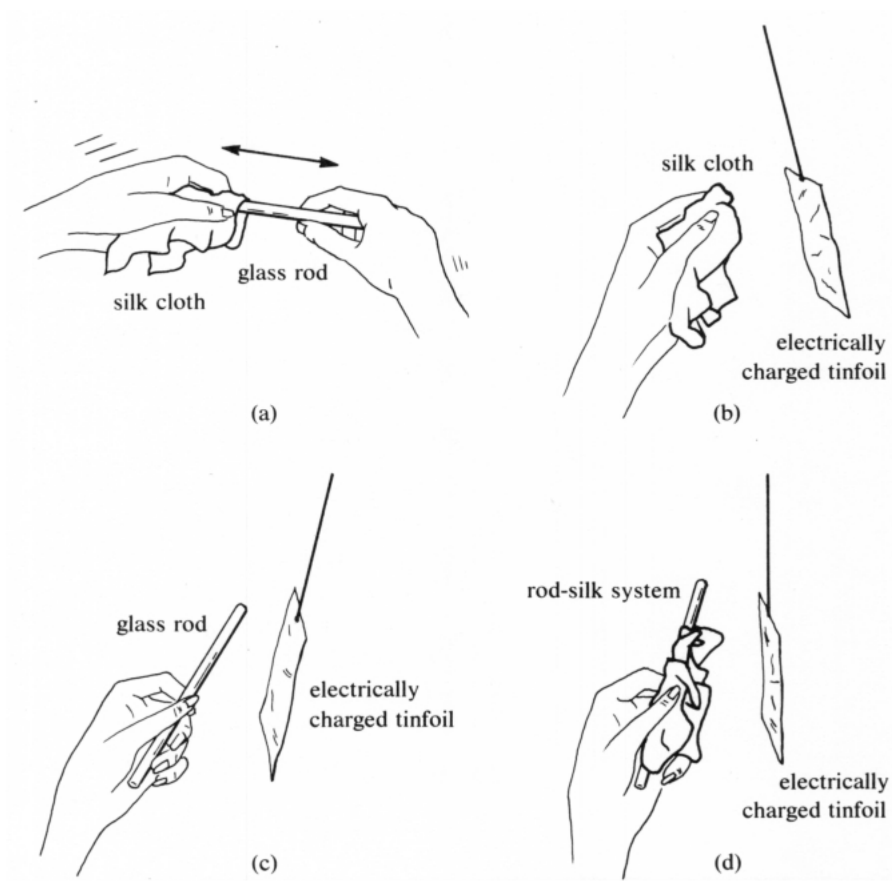
Figure 3.18 Hard rubber rods brushed with fur and glass rods rubbed with silk are permitted to interact. One rod is suspended by a silk thread and is free to rotate. The other rod is brought near until movement gives evidence of interaction.

Two-fluid model for electric charge. Two working models for electrically charged objects were proposed. One model assumed the existence of two different kinds of electric fluids or "charges" (a word for electrical matter) that could be combined with ordinary matter. Charges of one kind repelled charges of the same kind and attracted charges of the other kind.

Franklin's experiment. In a highly original experiment, Franklin found that the two kinds of charges could not be produced separately, but were formed in association with one another. Thus, when an uncharged glass rod and silk cloth are rubbed together, both objects become charged, but with different charges (Fig. 3.19). When the silk is wrapped around the rod, however, the rod-silk system does not have an observable electric field, even though the two objects separately do. Therefore, Franklin concluded that the two kinds of charges were opposites, in that they could neutralize each other. Accordingly, he called them "positive" and "negative," the former on the glass rod, the latter on the silk (and on the ebonite). Combined in equal amounts in one object, positive and negative charges add to zero charge. An object with zero charge is uncharged or electrically neutral.

One-fluid model for electric charge. Franklin's model, to explain this observation, provided for only a single "electric fluid." Uncharged objects have a certain amount of this fluid. Positively charged objects have an excess of the fluid, whereas negatively charged objects have a deficiency. When two uncharged objects are charged by being rubbed together, fluid passes from the one (which becomes negative) to the other (which becomes positive). The fluid is conserved (neither

Figure 3.19 Franklin's experiment.
(a) A glass rod is charged by rubbing a piece of silk.
(b) The silk is tested for electric charge by interaction.
(c) The glass rod is tested for electric charge.
(d) The rod-silk system is tested for electric charge.



created nor destroyed), so the two objects together have just as much fluid as at the beginning of the experiment; hence they form an electrically neutral system. Clearly the isolation of one or two electric fluids would be an exciting success of these models. We will pursue this subject further in Chapters 8 and 12.

Summary

Pieces of matter (objects) that influence or act upon one another are said to interact. The changes that occur in their form, temperature, arrangement, and so on, as a result of the influence or action are evidence of interaction. For the study of interaction, pieces of matter are mentally grouped into systems to help the investigator focus his attention on their identity. As he gathers evidence of interaction, the investigator compares the changes he observes with what would have happened in the absence of interaction. Sometimes he may carry out control experiments to discover this; at other times he may draw on his experience or he may make assumptions.

Pieces of matter that interact without physical contact are interacting-at-a-distance. Radiation and fields have been introduced as working model intermediaries for interaction-at-a-distance. The gravitational field, the magnetic field, and the electric field are the fields important in the macro domain. All three fields have associated with them a direction in space.

List of new terms

interaction	variable factor	field
system	inertia	gravitational field
conservation	inertial mass	magnetic field
state	inertial balance	electric field
evidence of interaction	radiation	magnetic pole
control experiment	interaction-at-a-distance	electric charge

Problems

1. What evidence of interaction might you observe in the following situations? Identify the interacting objects, identify systems (or subsystems) that show evidence of interaction, and describe what would have happened in the absence of interaction.
   (a) A man steps on a banana peel while walking.
   (b) A young man and a young woman pass each other on the sidewalk.
   (c) Two liquids are poured together in a glass.
   (d) A professor lectures to his class.
   (e) A comet passes near the sun.
   (f) Clothes are ironed.

2. Give two examples of interaction where the evidence is very indirect (and possibly unconvincing).
3. Do library research to find what role the interaction concept or other concepts of causation played (a) in Greek philosophy, (b) during the Middle Ages, (c) during the Renaissance, (d) in an Asiatic culture, (e) in a contemporary culture of your choice, and (f) in biblical literature.
4. Interview four or more children (ages 6 to 10 years) to determine their concepts of causation. Raise questions (accompanied by demonstrations, if possible) such as "What makes the piece of wood float?" "What makes the penny sink?" "What makes the clouds move?" "What makes an earthquake?" "What makes rain?" "Can rainfall be brought about or prevented?" (If possible, undertake this project cooperatively with several other students so as to obtain a larger collection of responses.)
5. Give two examples from everyday life of each of the following, and describe why they are appropriate. (Do not repeat the same example for two or more parts of this problem.)
   (a) Systems of interacting objects
   (b) Systems of objects that interact-at-a-distance
   (c) "Control experiments" you have carried out as part of an informal investigation
   (d) Systems that have social inertia
   (e) Systems that have thermal inertia
   (f) Systems that have economic inertia
   (g) Systems that have inertia of motion
6. Analyze three or four common "magic" tricks from the viewpoint of conservation of matter (rabbit in a hat, liquid from an empty glass, etc.).
7. Answer the questions in the margin on p. 59 and explain your answers.
8. Interview four or more children (ages 5 to 8 years) to determine their concept of the conservation of matter. (For suggestions, refer to B. Inhelder and J. Piaget, *The Growth of Logical Thinking from Childhood to Adolescence*, Basic Books, New York, 1958.)
9. Explain how various professions might define systems that are "conserved." Do not use the particular examples in Section 3.3.
10. Compare the use of the word "state" in the phrases "state of a system" and "state of the nation."

11. Propose a systematic series of experiments, other than the one described in Fig. 3.3, to identify the "guilty" circuit breaker.
12. Radiation and fields are introduced as models for intermediaries in interaction-at-a-distance. Describe your present preference for treating interaction-at-a-distance with or without such a model.
13. Four compasses are placed on a piece of cardboard that conceals some small bar magnets. How many magnets are under the cardboard? Locate their poles. Justify your answer. The compass needle directions are shown in Fig. 3.20, below.

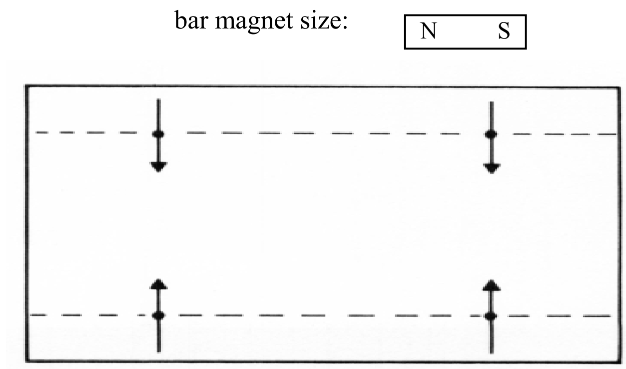


Figure 3.20 Compass needles near concealed magnets (Problem 13).

14. Comment on your present preference for one or the other of the two models described for electrical interaction: the two-fluid model and Franklin's one-fluid model.
15. Describe necessary features of a one- or two-fluid model for magnetized objects. Point out its advantages and disadvantages compared to the pole model.
16. Construct an operational definition for the direction of the electric field.
17. In Section 1.1, "matter" was left as an undefined term. It has been suggested that matter is "anything capable of interaction." Compare this definition with your intuitive concept of matter in the light of Chapter 3, especially Section 3.5. Comment on the logic of this definition, keeping in mind the definition of "interaction." Comment also on the effect of this definition on the conservation of matter principle.
18. Identify one or more explanations or discussions in this chapter that you find inadequate. Describe the general reasons for your dissatisfaction (conclusions contradict your ideas, or steps in the reasoning have been omitted, words or phrases are meaningless, equations are hard to follow, etc.) and pinpoint your criticism as well as you can.

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