# *APPENDIX 4: FIELDS*

**SLA**
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## Appendix 4.1: Vertical Motion at the Earth's Surface

For these questions, use **$g = -9.80$ m/s$^2$**. Assume that air friction is negligible.

1. A stone is dropped from a bridge to the water below. If it takes 2.45 s for the stone to hit the water, calculate the distance the stone fell.

2. A baseball is popped straight up. The ball leaves the bat moving at 37.8 m/s.
   a) How long does the catcher have to get in position to catch the ball at the same height as the bat struck the ball?
   b) To what height did the ball rise?
   c) At what time, after being struck, is the ball moving at 10.0 m/s upwards? Where is the baseball at this time?
   d) At what time, after being struck, is the ball moving at 10.0 m/s downwards? Where is the baseball at this time?
   e) What is the velocity of the ball when it is caught?
   f) At what time is the ball 20.0 m above the ground?
   g) Where is the ball 4.19 s after being hit?

3. An astronaut on the Moon accidentally drops a camera from a height of 1.60 m.

$$g_{moon} = -1.62 \text{ m/s}^2$$

   a) How long will it take before it strikes the lunar surface?
   b) If the astronaut were training on Earth, how long does it take for the fall?
   c) How fast is it moving when it strikes the surface of the Moon?

4. Food aid on a skid is dropped from an airplane flying horizontally at 125 m/s. The food skid falls for 18.6 s before it hits the ground.
   a) From what height was the food dropped?
   b) What is its vertical velocity when it strikes the ground?
   c) How fast is it travelling horizontally when it strikes the ground?
   d) How far did the food fall during the fifth second after being released?

## Problem Set Answer Key:

1. –29.4 m

2. a) 7.72 s
   b) 73.0 m
   c) 67.9 m
   d) 67.8 m
   e) –37.8 m/s
   f) $t_1$ = 0.571 s    $t_2$ = 7.14 s
   g) 72 m above the ground

3. a) 1.405 s
   b) 0.927 s
   c) –3.45 m/s

4. a) 630 m
   b) –183 m/s
   c) 125 m/s in original direction of motion
   d) –44 m (44 m downwards)

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## Appendix 4.2: Journal Entry: Gravitational Fields

1. Complete the Three-Point Approach for the following terms.
   - a) gravity
   - b) field
   - c) force of gravity
   - d) weight
   - e) gravitational field
   - f) g
   - h) altitude
   - i) latitude
   - j) free-body diagram
   - k) acceleration due to gravity
   - l) weightlessness
   - m) mass
2. Gravity is the major concept in this section. Putting gravity at the centre, draw a Concept Map showing how all the terms in Question #1 fit into your scheme for understanding gravity.
3. A stone of mass 75.0 g is dropped from the top of a 10-storey building with a height of 32.1 m. Calculate:
   - a) the velocity with which the stone hits the sidewalk below.
   - b) the time elapsed from the instant the stone is dropped until it strikes the sidewalk.
   - c) the weight of the stone.
4. From Question #3, calculate the velocity with which the stone hits the sidewalk if the stone was initially thrown upwards at 12.5 m/s.
5. From Question #3, calculate the final velocity with which the stone hits the sidewalk if only a constant force of air friction of 0.4 N acted on the stone.
6. a) Why is ***‘g’*** at a planet’s surface different for different planets?
   b) What kind of planet would have about the same value of **g** at its surface as Earth? Justify your answer based on your ideas from Part A.

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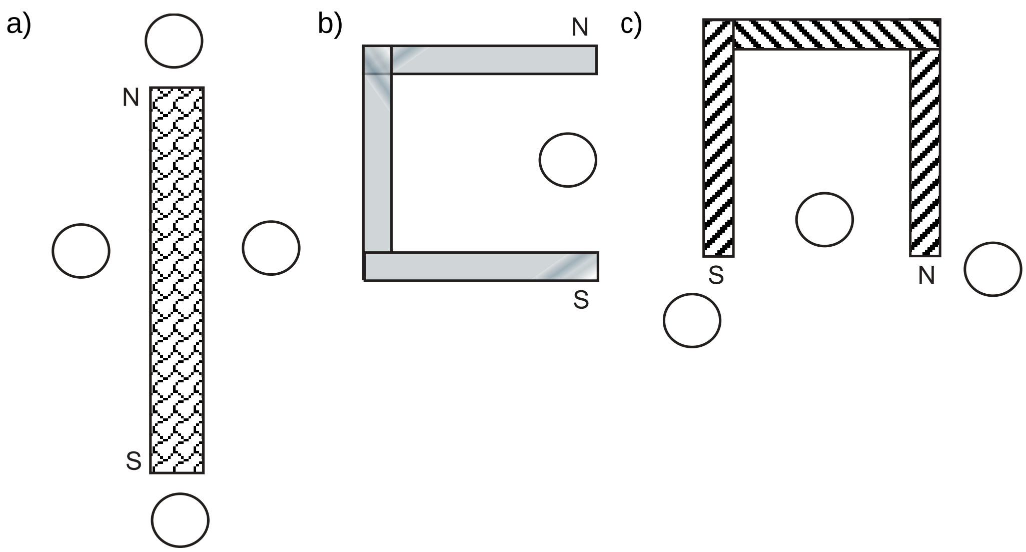
# Appendix 4.3: Student Sampler: Magnetic Fields

1. Given a bar magnet and an unmagnetized piece of iron that to the naked eye seem identical, describe how you would determine which object is magnetized:
   a) using a third object of your choice.
   b) using only the two objects.
2. Describe how a piece of iron can be made into a permanent magnet. Describe the process used outside the magnet and describe what is happening inside the magnet.
3. What is a domain?
4. Describe what happens if a bar magnet is cut into three equal lengths.
5. In the diagrams below, each circle represents a compass. Show the direction of the needle in each compass.




6. What is an ***angle of declination***? What implication does it have in the use of a compass?
7. Sketch the magnetic field around
   a) a bar magnet
   b) the poles of a horseshoe magnet
   c) two north poles pushed close together
   d) Earth

8. The pointed end of an iron nail is held close to the 'S' pole of a magnet.
   a) Which end of the nail becomes 'N'?
   b) Name the process that makes the nail a temporary magnet.
9. Apply the domain theory to explain each of the following:
   a) A nail can be magnetized by stroking it with a strong permanent magnet.
   b) When a magnet is being magnetized, it reaches a point called saturation where it cannot become any stronger.
   c) A magnet can be demagnetized by being hammered repeatedly.
   d) An iron magnet can be demagnetized by being heated to 770°C.
10. In terms of magnetic properties, distinguish between soft iron and hard iron.
11. Name the three most important magnetic chemical elements. What is it in these atoms that makes them magnetic in nature?
12. Distinguish among ferromagnetic, paramagnetic, and diamagnetic materials.

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# Appendix 4.4: Student Article Analysis—Scientific Fraud?

## Flirting with Fraud: Millikan, Mendel and the Fringes of Integrity

by Douglas Allchin (1992)

Fraud in science has deluged the public lately: with the David Baltimore/ Immanishi-Kari case, cold fusion (Pons and Fleischmann), and allegations against Gallo's priority claims in discovering the AIDS virus. And, with the reporting system in the Human Genome Project being largely unmonitored, can we expect new charges of abuses to be far behind? Many universities, following guidelines established by NSF, now have committees on "scientific integrity," and NSF has sent investigative teams to spot check some of the more active research institutions receiving federal funds.

The depth of fraud historically has been documented (though still quite incompletely) by journalists William Broad and Nicholas Wade in their 1982 *Betrayers of the Truth* (includes an appendix summarizing 34 cases). But careful examination of these cases can also pose some provocative questions about "proper" science. Consider, for example, the classic case of Gregor Mendel, whose published data on inheritance in pea plants, according to statistician Fisher, were too good to be true. Mendel's results were a one in a million chance. Some defend Mendel, though, saying that he followed contemporary practice: to repeat experiments, refine own's technique, and then use only the best results as the most representative ones. If that is not legitimate now, why not? What does this reveal about how we evaluate evidence? It is worth noting for ourselves, in fact, that the standards themselves have changed. Why?

A question worth posing for discussion is:

> If a scientist gets the "right" answer, does it matter if the data were "tweaked," "massaged," distorted, or even wholly fabricated?

The case of Robert Millikan, whose renowned oil-drop experiment established the value of the fundamental unit charge, e (and earned him the Nobel Prize in 1923), is far more provocative.

Millikan, of course, kept detailed notebooks of his laboratory activities, data and assessments of results. Several years ago, an effort to reconstruct Millikan's "exemplary" experimental thinking revealed serious discrepancies between Millikan's notebooks and his published "raw" data (Holton, 1978). The numerous notes which are scattered across the pages cast further doubt on Millikan's integrity:

*This is almost exactly right & the best one I ever had!!!* [20 December 1911]
*Exactly right* [3 February 1912]
*Publish this Beautiful one* [24 February 1912]
*Publish this surely/Beautiful!!* [15 March 1912, #1]
*Error high will not use* [15 March 1912, #2]
*Perfect Publish* [11 April 1912]
*Won't work* [16 April 1912, #2]

*Too high by 1½%* [16 April 1912, #3]
*1% low*
*Too high e by 1¼%*

Millikan had apparently been calculating the values of e for each set of observations as he went along, and comparing them with his expected value. Further, he seemed to use the match with the theory that he was supposedly testing as a basis for including or excluding results as the very evidence for that theory! As Franklin (1986) has noted, “we are left with the disquieting notion that Millikan selectively analyzed his data to support his preconceptions” (p. 141; echoing Holton 1978). Are we to conclude that Millikan’s analysis, laden with theoretical bias and which seems to treat experimental facts so casually, reflects the nature of scientific “genius”?

The notebooks reveal that, indeed, substantial data are missing from Millikan’s published reports. Of 175 total drops documented in the notebooks, only 58 (barely one-third) appear in the final paper. By contrast, Millikan had announced in his 1913 paper that “It is to be remarked, too, that this is not a selected group of drops but represents all of the drops experimented on during 60 consecutive days, during which time the apparatus was taken down several times and set up anew.” In his 1917 book, *The Electron*, he repeats this statement and then adds, “These drops represent all of those studied for 60 consecutive days, no single drop being omitted.”

At first blush, this outrageous violation of scientific integrity would seem to discredit Millikan’s findings. Even if one assumes that standards of reporting data earlier in the century were less rigorous, Millikan clearly misrepresented the extent of his data. One may caution, however, that we may not want to conclude that therefore there was no good, “scientific” basis for his selective use of data. A more complete analysis of Millikan’s notebooks, in fact, and of the nature of the experimental task that they crudely document, reveals more tellingly the reasons that Millikan included some drops and excluded others.

Physicist-philosopher Allan Franklin has addressed the problem by using Millikan’s original data to recalculate the value of e. Even when one uses various constellations of the raw data, Millikan’s results do not change substantially. That is, their accuracy was not severely affected by Millikan’s choice of only a subset of the observations. Millikan’s selectivity, at most, gave a false impression of the variation in values or the range of “error” in the data and, therefore, of the statistical precision of the computed value.

In fact, Franklin notes, Millikan threw out data that were “favorable” as well as “unfavorable” to his expectations. Clearly, Millikan’s results were over-determined. That is, he had more data than he needed to be confident about his value for the electron’s charge. Here, the redundancy of data was an implicit method for safeguarding against error. Thus, what appears as fraud from one perspective becomes, from an experimental perspective, a pattern of good technique.

One may examine further specifically when the observations that Millikan excluded occurred. The first 68 observations, for instance, were omitted entirely. Why? Following February 13, 1912 (which marks the first published data), one may also note, the number of excluded results decreases as the series of experiments proceeds. Apparently, Millikan became more skilled as time went on at producing stable, reproducible data. Prior to February 13th, one may infer, he was still working the "bugs" out of the apparatus and gaining confidence in how to produce trustworthy results. That is, he was testing his equipment, not any theory of the electron or its charge. Here, the notebooks help focus our attention on the apparatus and the material conditions for producing evidence, not the role of the evidence itself.

Millikan's comments in the notebooks highlight the significance of experimental judgements, especially in excluding particular observations. For example, "Beauty Publish," on April 10, 1912 is crossed out and replaced by, "Brownian came in." Here, the way the drop had moved meant that his measurements did not reflect the values Millikan needed for his calculations—those which the apparatus, of course, was specifically designed to produce. Millikan's judgement about other aspects of the experimental set-up are revealed elsewhere:

*This work on a very slow drop was done to see whether there were appreciable convection currents. The results indicate that there were. Must look more carefully henceforth to tem[perature] of room.* [19 December 1911]

*Conditions today were particularly good and results should be more than usually reliable. We kept tem very constant with fan, a precaution not heretofore taken in room 12 but found yesterday to be quite essential.* [20 December 1911]

*Possibly a double drop.* [26 January 1912]

*This seems to show clearly that the [electric] field is not exactly uniform, being stronger at the ends than in the middle.* [27 January 1912]

*This is good for so little a one but on these very small ones I must avoid convection still better.* [9 February 1912]

*This drop flikered as tho unsymmetrical.* [2 March 1912]

*This is OK but volts are a little uncertain and tem also bad. It comes close to lower line.* [7 March 1912, #1]

Millikan had thus been concerned about several parameters critical for obtaining "good" or "clean" results, consistent with the design of the experiment: the size and symmetry of the drop; convection currents (temperature of room); smoothness of movement of the drop; and (elsewhere) dust, pressure and voltage regularity (Franklin, pp. 149-50).

Even where he could not pinpoint the problem, he might sense that "something the matter . . ." [13 February 1912]. Millikan's confidence in his judgement meant that in some cases he did not even go on to calculate e, excluding those observations even before seeing the "results." In other cases, he recognized the "beauty" of the run:

*Beauty. Tem & cond's perfect. no convection. Publish* [8 April 1912]

Millikan's decisions to publish data (or not) based on their "beauty" (above), therefore, probably reflected his assessments of the particular experimental conditions. His striking comment on February 27, 1912, "Beauty one of the very best," may thus refer, not to the value of e itself, but to the quality of his own technique.

Millikan excluded other events based on the methods of calculation. For example, the formula used a substituted value based on certain theoretical assumptions in Stokes's Law (relating pressure, air viscosity and drop radius). While Millikan tolerated the first-order "corrections" for the values, in 12 cases where unusual data required him to rely on less certain second-order corrections, he simply omitted the events. In other words, not all data were "user-friendly"—that is, tailored to the framework for drawing legitimate conclusions.

Millikan was also able to exploit the fact that the value of e could be calculated in two ways, each using slightly different measurements of the same event. He allowed the two methods to cross-check each other. In some cases, he noted:

*Agreement poor. Will not work out.* [17 February 1912, #3]

*Error high will not use. . . . Can work this up and prob is OK but point is not important. Will work if have time Aug. 22* [15 March 1912, #2]

Again, where he found discrepancies, he was better off avoiding the possible uncertainties by simply sidestepping the "unworkable" events. By the end of the experimental period, one can sense that Millikan, having more than enough data, was continuing his work merely to build confidence about all his safeguards. Three days before he stopped taking observations, he satisfied himself, "Best one yet for all purposes" [13 April 1912]. Two days later, the very day before ending, he recorded:

*Beauty to show agreement between the two methods of getting* $v_1 + v_2$ *Publish surely* [15 April 1912]

An aim of internal consistency, rather than agreement between theory and data, clearly guided Millikan's work.

Even the final values of the calculations could themselves be clues or signals that something was amiss. One erratic value of e—clearly outside the boundary of typical or “reasonable” values, or of anything else he had found to date—prompted Millikan to decide: “could not have been an oil drop” [20 December 1911 #3], and to conclude apparently that it was a dust particle. Millikan excluded two other important drops that gave anomalous values of e, even though one, by Millikan’s own judgement, was a model of consistency. Having begun with some confidence:

*Publish. Fine for showing methods of getting v* [16 April 1912, #2]

He later marked in the corner of the page (without further accounting), “Won’t work.” In retrospect, Millikan’s intuition seemed to have served him well: we know from data in Millikan’s notebook that these two drops had unusually high total charges and that such drops (as we have learned since 1912) are not reliable using the method that Millikan used. Here, again, Millikan’s primary reasoning concerned whether to trust the apparatus and his experimental measurements—not (yet) whether the theory or value of e itself was correct.

The use of Millikan’s oil drop experiment in class labs can easily suggest to students that it was quite trivial—what with a novice being able to reproduce the work of a Nobel Prize winner, after all! The current standardization of the experiment disguises, though, the complexity of the context in which it developed. Conceptually, the task in the early 1900s was relatively clear. Indeed, Millikan’s experimental strategy in 1910-1912—to observe drops of fluid, each laden with charge, moving in an electric field—had been tried by many researchers before. The chief difficulties at the time lay in the mechanics of constructing the situation idealized by theory. Millikan’s ultimately successful strategy differed from others by focusing on single drops and by substituting water with oil, which did not evaporate so easily and thus made more sustained observations possible. That is, Millikan’s achievement, marked by the Nobel Prize, was largely technical.

An analysis of Millikan’s notebooks, therefore, highlights a grey zone between outright misrepresentation of data and skilled experimental “micro-reasoning.” Was Millikan’s selective use of data “good” science? One may contrast Millikan and his success, in this case, with his critic, Felix Ehrenhaft, who stubbornly resisted discarding the results of any run. Was Ehrenhaft’s experimental posture appropriately conservative or unduly myopic? Was Millikan, likewise, inexcusably dishonest or justifiably pragmatic?

The question of whether editing of data can represent good science is obviously aggravated by cases where they have failed to yield reliable conclusions. Stephen Jay Gould (1981, pp.56-60) notes that in studying the relative cranial capacity of Caucasians and “Indians,” a 19th-century investigator excluded many Hindu skulls...but for “good” reasons? The “Hindoo” braincases were too small and, because they were “clearly” unrepresentative of the Caucasian population he wanted to sample, they would “bias” his results. Here the effect of the selection was probably not even conscious. Likewise, anthropologists in the same era, evaluating women's skulls, relied on their "intuitions" to disregard types of measurements that suggested that women (or elephants, whales or bear-rats) were more intelligent than men. So, can one know where selection is legitimate, and where not?

The cases of Millikan and Mendel illustrate, in particular, that in answering such a question, we must focus on experimental skills and judgement (and on apparatus) as much as on the concepts themselves. While this is the potential "lesson," though, the problem that sparks the inquiry may be the spectre that fraud is the very tool of genius.

## Further Reading


- Fisher, R.A. 1936. "Has Mendel's Work Been Rediscovered?" *Annals of Science* 1:115-137. Reprinted in C. Stern and E. Sherwood (eds.), *The Origins of Genetics: A Mendel Source Book* (W.H. Freeman, 1966).
- Franklin, Allen. 1981. "Millikan's Published and Unpublished Data on Oil Drops." *Historical Studies in the Physical Sciences* 11:185-201. Also discussed in Chap. 5 of *The Neglect of Experiment* (Cambridge Univ. Press, 1986).
- Gould, Stephen Jay. 1981. *The Mismeasure of Man*. W.W. Norton.
- Holton, Gerald. 1978. "Subelectrons, presuppositions and the Millikan-Ehrenhaft Dispute." *Historical Studies in the Physical Sciences* 9:166-224. Reprinted pp. 25-83 in *The Scientific Imagination* (Cambridge Univ. Press, 1978).

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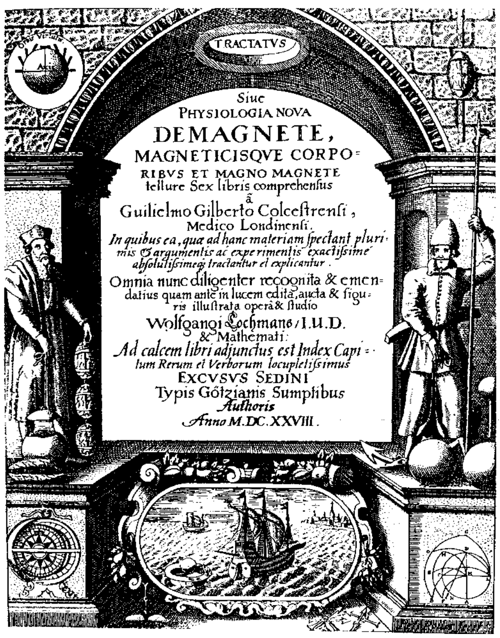
# Appendix 4.5: William Gilbert and the Earth's Magnetic Field

> ". . . magnetick force is animate, or imitates life: and in many ways surpasses life which is bound up in the organick body."
>
> William Gilbert (1600)
> from his *Physiologia Nova de Magnete*

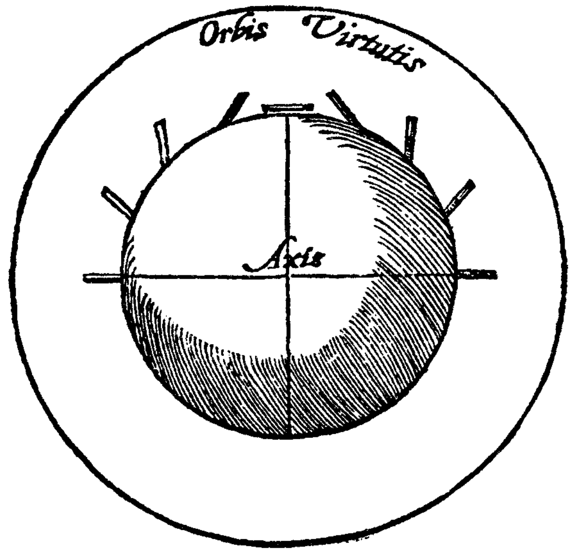
Sir William Gilbert personifies the "Renaissance man" in that he had a wide-ranging set of interests, and ended up by making his greatest contributions outside of his chosen vocation—medicine. During the latter part of the 16th century, the separation between what was called "craft" (we would call it technology) and "scholastics" (philosophical/intellectual work) was beginning to break down. There was no scientific method of enquiry as we have come to know it today—no experimental rigour, creation of theories, testing of hypotheses, theoreticians, et cetera. Nevertheless, the scholars of the day supplied the craftspeople with the theory they lacked. This is where William Gilbert made a noble contribution to natural philosophy (we call it "science").




Building on the observations of a retired London mariner and compass-maker, Gilbert sought the answers to how magnetic materials functioned. Natural magnets—called "lodestones"—had been around since antiquity. Indeed, our word "magnet" derives from the Greek *ho Magnes lithos*, meaning "the Magnesian stone," which were abundant in what is now northern Greece. Gilbert, the court physician to Queen Elizabeth I, was fascinated with the experiments of Robert Norman (the compass-maker)—particularly those dealing with the magnetic inclination or the dip of a freely suspended compass needle. Gilbert fashioned spherical lodestones to which he gave the intriguing name *terrellas* (little Earths), and proceeded to demonstrate exhaustively any magnetic phenomena.

Among his many observations, Gilbert found that, like a mariner's compass needle, small magnetic iron needles rested on the surface of a terrella with a dip angle related to the position of one of the magnetic poles (see his sketch on the following page).

"Variety in the Inclinations of Iron Spikes at Various Latitudes of a Terrella"




You may have noticed that Gilbert included an *orbis virtutis* (the sphere of virtue) above the surface of the terrella. He believed that the magnetic field of a lodestone was somehow coupled to the surface by what he called a *coition*. Later on, this *orbis virtutis* was to provide the force necessary to cause the Earth's diurnal (daily) rotation on its axis. The 13th-century writer, Pierre de Maricourt, had suggested that spherical magnetic bodies spontaneously rotate about their magnetic axes. Though he never saw this phenomenon, he declared openly:

> ". . . the Great Magnet of the Earth turns Herself about
> by Magnetick and Primary virtue . . ."

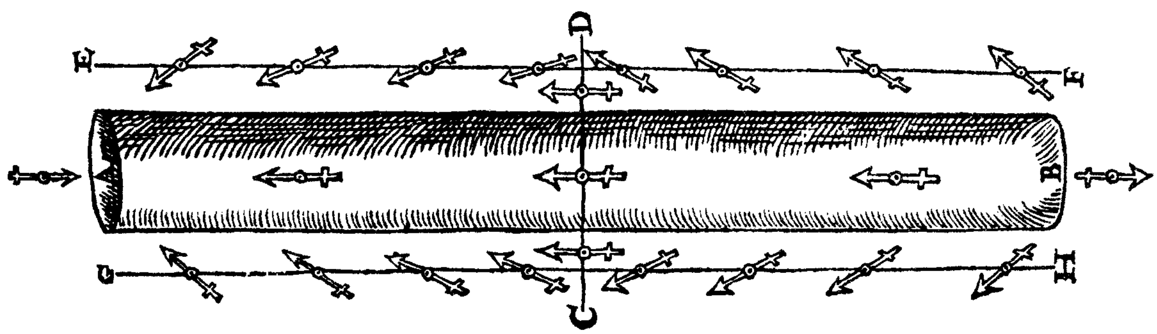
From Gilbert's point of view, the Earth's magnetism reached to the heavens and was responsible for holding the Earth together. In Newtonian terms, then, terrestrial gravity was simply magnetism.

> ". . . the magnetick diurnal revolution of the Earth's
> globe is a possible assertion against the time-honoured
> opinion of a Primum Mobile . . ."

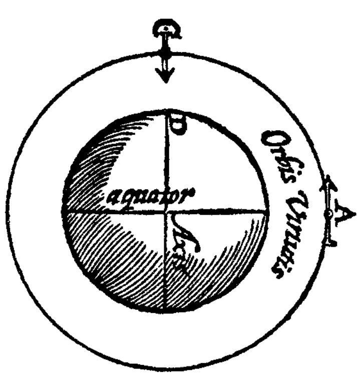
With his magnum opus *de Magnete*, Gilbert ushered in a new era where empirical study and the theoretical interpretation of nature would merge in a novel way. Francis Bacon later pointed out that even though Gilbert conducted many "experiments," his work was noticeably speculative. Instead of using his hypotheses to influence his experimental work, Gilbert formulated his theories after his experimental work had been completed and did not devise further investigations that would give substance to his conclusions. Despite these criticisms, Renaissance natural philosophy owes a great deal to this man's work—for he struggled with a reasoned approach to the visible universe. In the sense that he tried to reconcile technology of the day to the high-minded principles of natural philosophy, Gilbert was indeed a “Baconian” in his methods, even if a certain naïveté existed in his procedures.

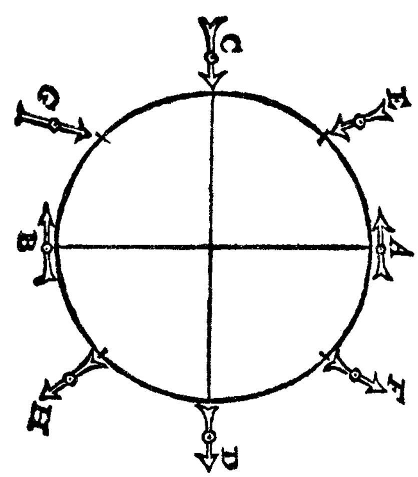
Perhaps his greatest insight was his vision of the Earth as a “great magnet” that was **dipolar**. By duplicating with his terrella many of the observations known from nautical experience, Gilbert was convinced that the Earth’s composition was similar to a great, spherical lodestone with two magnetically opposed poles. Sir William developed the view of the solid Earth as being like an enormous lodestone.

We know that the mineral **magnetite ($Fe_30_4$)** predominates in his terrellas, and it is interesting that today most geophysicists support the idea that the Earth’s liquid, metallic outer core is composed primarily of iron and nickel with a solid iron inner core beneath it. Today, many are in agreement that the fluid motions in the Earth’s outer core are responsible for the generation of the magnetic field of the planet (the so-called **geodynamo**). It is remarkable to think that we still have a very poor understanding of the source of the Earth’s magnetic field, and work with modern-day “terrellae” to model fluid motions in the outer core.



“. . . a lodestone attracts magneticks not only to a fixed point or pole, but to every part of a terrella save the æquinotial zone . . .”



Since William Gilbert was a contemporary of Galileo Galilei, Johannes Kepler, and Tycho Brahe, it is not surprising that he had opinions about the large-scale structure of the universe and was familiar with these luminaries of the early 17th century. In fact, he adopted the Tychonian system that consisted of the five planets revolving around the Sun, and that this system in turn was in circular motion about a fixed Earth. There was one notable exception, however; Gilbert suggested that the Earth underwent diurnal rotation. Perhaps he had in mind that the magnetic field of the Earth was the motive force driving the entire cosmos!

> ". . . for in the oldest mines of iron, the most famous at Magnesia in Asia, the lodestone was often dug out with its uterine brother, iron . . ."

The activities that follow are designed to aid the student in "discovering" the magnetic field of the Earth. Indeed, most were demonstrated by Gilbert himself. As the students make their way through each of them, encourage them to use brief sketches as much as possible along with observational statements. This may help to visualize a model of the Earth's magnetic field that accounts for what they see.

## Activity Sequence: Earth's Magnetic Field

### Activity 1: Magnetic Poles

- Examine a bar magnet and notice that it is marked with an 'N' on one end and an 'S' on the other end. What do these letters mean?
- Suspend the bar magnet with a piece of dental floss so that it rests horizontally above the floor. Give the magnet a few turns, let go of it, and observe the direction the end marked 'N' points to when it comes to rest again.
- Repeat this at least three more times and make a statement about what you observed. Record all results carefully, and include sketches.

### Activity 2: Magnetic Compass Needle

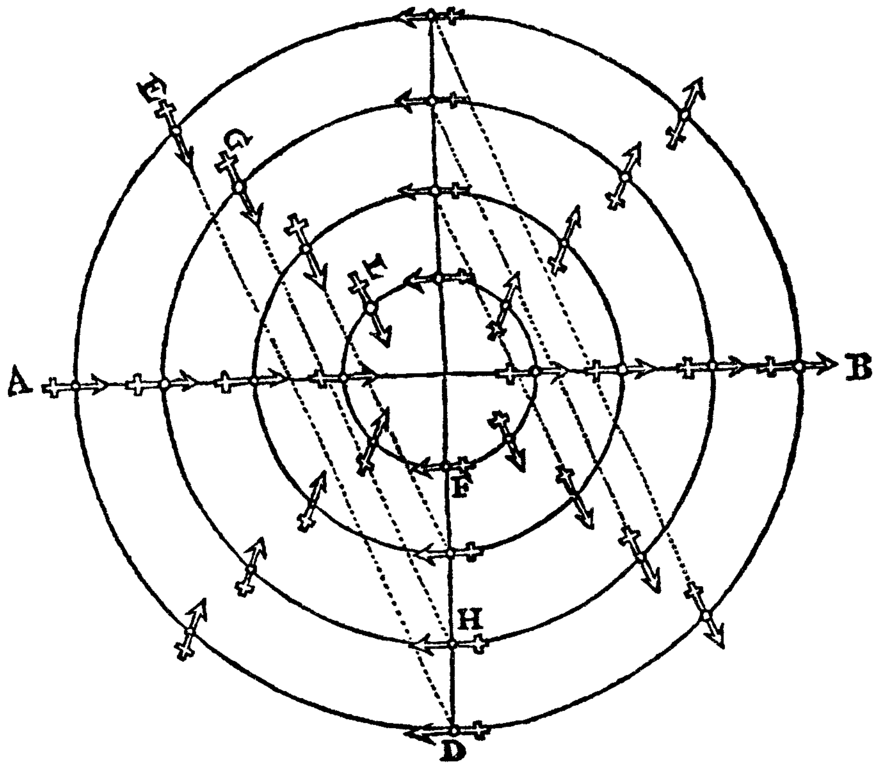
- Using the pivot-mounted compass needle, repeat the procedure from the previous activity. First, cause the needle to rotate on its pivot and record the direction of the pointer after it comes to rest.
- Make a statement about your findings, and compare with those from Activity 1.

### Activity 3: Nature of "Like" and "Unlike" Poles

- Using the suspended bar magnet, bring the 'N' pole of a second magnet near (but not touching) the 'N' pole of the suspended magnet. What do you see happening?
- Repeat this procedure for the 'S' pole of the test magnet (i.e., reverse the ends). What do you observe? Make a prediction about what will happen if you repeat these two steps at the 'S' pole of the suspended magnet.
- Test your predictions. Did you observe what was expected from your predictions?
- Make brief sketches and note your observations alongside your sketches. Are there any general conclusions that can be made from this activity?
- Using the small compass available, repeat the above steps and compare/contrast the observations with those using the bar magnet. Is there a certain behaviour for **magnetic poles** that is common to both sets of observations in this activity?

### Activity 4: Mapping a Magnetic Field

- This activity simulates one of the important observations of Sir William Gilbert, and encourages you to develop your own conception of how the Earth's magnetic field should behave.
- Place a bar magnet on a sheet of large, white paper. Orient, if possible, the 'N' pole of the bar magnet with the magnetic north determined from Activities 1 and 2.
- Use a small magnetic compass for this procedure.
- Beginning near the 'N' pole and moving towards the 'S' pole at a distance of a few centimetres from the magnet, draw an arrow (↑→↓←↗↘↙↖) to indicate the orientation of the "north-seeking" pointer on the compass. You should have at least eight to ten arrows for one complete circle around the perimeter of the bar magnet.
- Repeat this procedure, but at a distance of twice that used above. Attempt to draw the arrows in approximately the same locations so that straight lines drawn through them would meet at the centre of the magnet.
- Repeat a third time at a distance of four times that used on the first trial.
- Attempt to draw "magnetic lines of force" that would outline the structure of the magnetic field. Compare your results with William Gilbert's original drawing shown on the following page. In what ways is your "map" similar to Gilbert's map? Do you notice any differences between the two?
- Generalize the above results and draw a sketch of what you suppose the Earth's magnetic field would look like if it were visible to the eye from space. As an interesting part of this, decide where you would put the 'N' and 'S' poles of the Earth's internal magnet. Make sure that your model is able to explain all of the characteristics of a magnet that you have demonstrated so far.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# Notes