25 Electromagnetic Induction

Photo openers begin with Professor Jean Curtis who taught at the University of Hawaii at Hilo. She never smoked, yet recently died of lung cancer. Photo 3 shows Z. Tugba Kahyaoglu engaged with her students. illustrating that engagement with students is the key to good instruction. Photo 4 shows Sheron Snyder, an early pioneer of Conceptual Physics with very young students—8th graders—successfully! Also via student engagement. She has for years shown that properly engaged, the concepts of physics are indeed comprehensible to students.

A personality profile on Michael Faraday nicely opens this chapter.

This chapter focuses on the important features of electromagnetic induction, and avoids such complications as reactances, back emf, Lenz's law, and the left and right hand rules that normally serve to overwhelm your students. An important function of the chapter is to implant the idea of transferring energy from one place to another without means of physical contact. The chapter should be supported with various lecture demonstrations of electromagnetic induction, such as those in the figures of the chapter.

Magnetic strips of credit cards are common to all. Interestingly, there is now a new generation of "smart cards" that use *ferroelectric* memories, rather than ferromagnetic ones. Similar to the alignment of magnetic domains in ferromagnetic strips, the surfaces of ferroelectric crystals retain a charge polarization.

This chapter serves as a background for the study of light.

Practicing Physics Book:
• Faraday's Laws
• Transformers

Problem Solving Book:
Ample problems for both this and the preceding chapter

Laboratory Manual:
• Generator Activator Generators (Activity)

Next-Time Questions:
• Induction Coils
• Power Saw

Hewitt-Drew-It! Screencast: •*Electromagnetic Induction*

The suggested lecture will probably span two or three class periods.

SUGGESTED LECTURE PRESENTATION

This lecture is a series of demonstrations.

Electromagnetic Induction

Up to this point you have discussed how one can begin with electricity and produce magnetism. The question was raised in the first half of the 1800s; can it be the other way around—can one begin with magnetism and produce electricity? Indeed it can, enough to light entire cities with electric lighting! Now you produce your galvanometer, magnet, and wire loop—conspicuously well away from your previous electric power source.

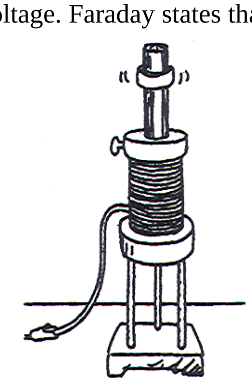
> DEMONSTRATION: Plunge a magnet in and out of a single coil, as in Figures 25.1 and 25.3, and show with a galvanometer the current produced. This is nice with a large lecture demonstration galvanometer.

This need not be mysterious, for it follows from the deviations of electrons in a magnetic field, as in the previous chapter. Invoke the argument shown in Figure 25.7. [Electrons are moved across the magnetic field lines when you push the wire downward, and they experience a sideways force. That's because this time there *is* a path for them and they move along the wire. Point out that this is the same physics as Figure 25.7a.] Then repeat with the wire bent into two coils—twice the effect. Many coils (Figure 25.3), many times more current.

> DEMONSTRATION: (Comparing times of dropping a small bar magnet versus an unmagnetized piece of iron through a vertical conducting pipe.) First, drop a small unmagnetized piece of iron through a vertically held copper or aluminum pipe. It drops quickly. Then do the same with a small bar magnet. Aha, the dropping time is appreciably longer. The explanation is that as the magnet falls through the conducting pipe, the pipe's inner surface experiences a changing magnetic field, which induces a voltage and hence a flow of charge (a current). This current produces its own magnetic field, which interacts with the falling magnet. The interaction is repelling, for the direction of any induced field *opposes the change in the inducing field*. This is *Lenz's law* (not treated in the chapter to minimize information overload). Interestingly, if the induced field were to enhance the change in the inducing field, the falling magnet would be attracted rather than repelled and its acceleration would increase, meaning a gain in KE greater than its decrease in PE. A conservation of energy no-no! (Both Arbor Scientific and Pasco Scientific have kits that features this demonstration.)

Faraday's Law

We have seen that charges moving in a magnetic field experience forces. In the previous chapter, the force deviated the direction of electrons, both in a free beam and traveling along a wire, in which case the wire was deviated. Now we see that if we push electrons that are in a wire into a magnetic field, the deviating force will be along the direction of the wire and current is induced. Another way to look at this is to say that *voltage* is being induced in the wire. The current then, is a result of that voltage. Faraday states that the voltage induced in a closed loop equals the time rate of change of the magnetic field in that loop—another way of looking at induction. So rather than saying current is induced, Faraday says voltage is induced, which produces current.



> DEMONSTRATION: Show the assorted demonstrations with the classical Elihu Thompson Electromagnetic Demonstration Apparatus. With the power on, levitate an aluminum ring over the extended pole of the Elihu Thompson device, as is shown in the photo of the late Jean Curtis in the chapter opener.

> CHECK QUESTION: Do you know enough physics to state how much electromagnetic force supports this 1-newton aluminum ring (assuming the ring weighs 1 N)? [Answer: 1 N, not

particularly from a knowledge of electromagnetic forces, but from knowledge about forces in general that go back to Newton's laws. Since the ring is at rest and not accelerating, the upward electromagnetic force (in newtons!) must be equal to the downward force of gravity.]

DEMONSTRATION: With the power off, place the ring at the base of the extended pole. When you switch the power on, the current induced in the ring via electromagnetic induction converts the ring into an ac electromagnet. (By Lenz's law, the polarity of the induced magnet is always such to oppose the magnetic field imposed.)

CHECK QUESTION: Do you know enough physics to state whether or not the electromagnetic force that popped the ring was more than, equal to, or less than the magnetic force that produced levitation earlier? [Answer: More, because it accelerated upward, evidence the upward force was more than the weight. This is also understandable because the ring was lower where it intercepts more changing magnetic field lines.]

As interesting examples of electromagnetic induction, consider Think and Explains 53, 54, 55, and 56 (smart traffic lights, airport metal detectors, and earthquake detectors).

Emphasize the importance of this discovery by Faraday and Henry, and how its application transformed the world. In today's world it's difficult to imagine having no electric lights—to live in a time when illumination after the Sun goes down is by candles and whale-oil lamps. On a long scales this was not so long ago, really. In our older cities many buildings still have pre-electric light fixtures that once used gas or oil.

State that underlying all the things discussed and observed is something more basic than voltages and currents —the induction of *fields*, both electric and magnetic. And because this is true we can send signals without wires—radio and TV—and furthermore, energy reaches us from the Sun, sunlight.

Generators and Alternating Current
Point out that strictly speaking generators do not generate electricity—nor do batteries. What they do is pump a fluid composed of electrons. As stressed in the previous chapter, they don't make the electrons they pump. The electron fluid is in the conducting wires.

DEMONSTRATION: Return to the motor from the previous lecture and show that when you reverse the roles of input and output, and apply mechanical energy, it becomes a generator. Light a bulb with the hand-cranked generator and show how the turning is easier when the bulb is loosened and the load removed. Then allow students to try this themselves during or at the end of class.

Compare motor and generator—in principle the same. When electric energy is the input and mechanical energy is the output, the device is a motor. When mechanical energy is put in it and electrical energy is the output, the device is a generator. In fact, a motor acts also as a generator and creates a "back voltage" (back emf) and an opposing current. The net current in a motor is the input current minus the generated back current. An interesting example of this back current occurs in a motor that overheats. The net current in a power saw will not cause its overheating and damage to its motor windings—so long as it is running and generating a back current that keeps the net current low. But if you should jam the saw so that it can't spin, without the back current generated by the spinning armature, the net current is dangerously high and can burn out the motor.

It is interesting that electric motors are used in diesel-powered railroad engines. The combustion engine cannot bring a heavy load from rest, but an electric motor can. Why? Because when the armature is not turning, the current in the windings is huge, with a corresponding huge force. As both the train and the motor gain speed, the back current generated by the motor brings the net current in the motor down to nonoverheating levels.

Stress the fact that we don't get something for nothing with electromagnetic induction, and acknowledge Figure 25.4. This can be readily felt when lamps powered with a hand-cranked or a bicycle generator are switched on. Each student should experience this. The conservation of energy reigns!

Power Production
Continue with a historical theme: With the advent of the generator the task was to design methods of moving coils of wire past magnetic fields, or moving magnetic fields past coils of wire. Putting turbines beneath waterfalls, and boiling water to make steam to squirt against turbine blades and keep them turning—enter the industrial revolution.

Transformers
Explain the operation of a transformer. (I remember as a student being very confused about the seeming contradiction with Ohm's law—the idea that when voltage in the secondary was increased, current in the secondary was decreased.) Make clear that when the voltage increases in the coil of the secondary and the circuit it connects, the current in *that* circuit also increases. The decrease is with respect to the current that powers the *primary*—in the other coil—which is the reason why $P = IV$ does not contradict Ohm's law!

> DEMONSTRATION: With a step-down transfer, weld a pair of nails together. This is a spectacular demonstration when you first casually place your fingers between the nail ends before they make contact, and after removing your fingers bringing the points together allowing the sparks to fly while the nails quickly become red and white hot.

Cite the role of the transformer in stepping down voltages in toy electric trains, power calculators, and portable radios, and the role of stepping up voltages in various electrical devices, and both stepping up and stepping down voltages in power transmission.

> CHECK QUESTIONS: Consider feeding about 10 volts DC into a primary coil, turning it off and on so current fluctuations show on a galvanometer in the secondary circuit. When the coils are spread farther apart, a tiny current still shows on the galvanometer. Do as Henry A. Garon does and ask if induction will still occur if the coils are a mile away? A hundred miles away? If so, doesn't this suggest that the primary acts like a radio station, and the secondary as a radio receiver? Interestingly, receiver antennas in the early days of radio were in fact wound as large-diameter coils atop the receivers!

Field Induction
Point to the similarity of the field induction laws of Faraday and Maxwell—how a change in either field induces the other. This concept led Einstein to the development of his special theory of relativity. Einstein showed that a magnetic field appears when a purely electric field is seen by a moving observer, and an electric field appears when a purely magnetic field is seen from a moving vantage point.

Because of the electric and magnetic induction of fields in free space we can "telegraph" signals without wires—hence radio and TV—and furthermore, we shall see that because of field induction, there is light.
My screencast on *Electromagnetic Induction* focuses on this historical view.

Answers and Solutions for Chapter 25

Reading Check Questions

1. Independently, they both discovered electromagnetic induction.
2. For electromagnetic induction to occur there must be a change in magnetic field intensity in the coil.
3. The induced voltage in a coil is proportional to the number of loops, multiplied by the rate at which the magnetic field changes within those loops.
4. Move the loop near a magnet; move a magnet near a loop; change the current in a nearby loop.
5. Both frequencies are the same.
6. The basic differences are input and output, so whereas a motor converts electrical energy into mechanical energy, a generator does the reverse.
7. Current is ac because the induced voltage is ac.
8. Common frequency is 60 hertz.
9. Faraday and Henry made the discovery, Tesla put it to practical use.
10. An armature is an iron core wrapped with bundles of copper wire.
11. Steam commonly supplies energy to a turbine.
12. No, a generator simply transforms energy from one form to another.
13. A MHD generator has no moving parts.
14. Yes, the flow of electric charged particles through a magnetic field induces voltage.
15. Power is the rate that energy is transferred.
16. No, a transformer boosts voltage, or reduces it, but not energy. That's a conservation of energy no-no!
17. A transformer changes voltage and current, but not energy and power.
18. Power input and output are the same.
19. A step-down transformer steps down voltage.
20. Output current is increased.
21. Operation depends on change, hence alternating current ac.
22. The advantage of ac is efficient voltage stepping up or down.
23. Yes, this is called self-induction.
24. High voltage means less current for a given amount of power, which means less wasteful heating of wires.
25. No wires are needed. Personal electronic devices attest to this.
26. James Clerk Maxwell extended Faraday's law.
27. An alternating electric field is induced.
28. An alternating magnetic field is induced.
29. No wires needed!
30. Light!

Think and Do

31. Open-ended.

32. Open-ended.

33. Cans contain iron. Domains in the can tend to line up with Earth's magnetic field. When the cans are left stationary for several days, the cans become magnetized by induction, aligning with Earth's magnetic field.

34. When dropping the magnet through the copper pipe, its motion induces a circular current in the pipe, which is accompanied by a magnetic field. This induced field opposes the field that produced it and the magnet is considerably slowed as it falls through. Yum!

Plug and Chug

35. $\frac{120\text{ V}}{10\text{ turns}} = \frac{x\text{ V}}{100\text{ turns}}$, where x = (100 turns) $\times \frac{120\text{ V}}{10\text{ turns}}$ = 1200 V.

36. $\frac{120\text{ V}}{100\text{ turns}} = \frac{x\text{ V}}{10\text{ turns}}$, where x = (10 turns) $\times \frac{120\text{ V}}{100\text{ turns}}$ = 12 V.

Think and Solve

37. $\frac{120\text{ V}}{500\text{ turns}} = \frac{6\text{ V}}{x\text{ turns}}$, $x\text{ turns} = 500\text{ turns} \times \frac{6\text{ V}}{120\text{ V}} = 25\text{ turns}$.

38. $\frac{120\text{ V}}{360\text{ turns}} = \frac{6\text{ V}}{x\text{ turns}}$, $x\text{ turns} = 360\text{ turns} \times \frac{6\text{ V}}{120\text{ V}} = 18\text{ turns}$.

39. From the transformer relationship,

$$\frac{\text{primary voltage}}{\text{number of primary turns}} = \frac{\text{secondary voltage}}{\text{number of secondary turns}} = \frac{120\text{ V}}{24\text{ V}} = \frac{5}{1}$$. So there are

5 times as many primary turns as secondary turns.

40. Since power in both the primary and secondary is the same, $IV_{prim} = IV_{sec}$, a 5 times greater voltage in the primary means 1/5 as much current as in the secondary. That's 1/5 × 1.8 A = 0.36 A. Then (120V)(0.36A) = (24 V)(1.8 A).

41. The transformer steps up voltage by a factor 36/6 = 6. Therefore a 12-V input will be stepped up to 6 × 12 V = 72 V.

42. (a) From the transformer relationship, $\frac{\text{prim voltage}}{\text{number of prim turns}} = \frac{\text{sec voltage}}{\text{number of sec turns}}$,

$$\text{sec voltage} = \frac{\text{prim voltage} \times \text{number of sec turns}}{\text{number of prim turns}} = \frac{12\text{ V} \times 250\text{ turns}}{50\text{ turns}} = 60\text{ V}$$

(b) From Ohm's law, current $= \frac{V}{R} = \frac{60\text{ V}}{10\text{ W}} = 6\text{ A}$.

(c) Power supplied to the primary is the same as the power delivered by the secondary;
Power = current × voltage = 6 A × 60 V = 360 W.

43. The voltage step up is (12,000V)/(120V) = 100. So there should be 100 times as many turns on the secondary as compared with the primary.

44. (a) Since $P = IV$, the current supplied to the users is

$$I = \frac{P}{V} = \frac{100,000\text{ W}}{12,000\text{ V}} = 8.3\text{ A}.$$

(b) Voltage in each wire = current × resistance of the wire = (8.3 A)(10 Ω) = 83 V.
(c) In each line, power = current × voltage = (8.3 A)(83 V) = 689 W. The total power wasted as heat is twice this, 1.38 kW.
(d) The 1.38 kW wasted as heat is a small and tolerable loss. If the transmission voltage were ten times less, the losses to heat in the wires would be 100 times more! Then more energy would go into heat in the wires than into useful applications for the customers. That would not be tolerable, which is why high-voltage transmission is so important.

Think and Rank

45. B, C, A
46. (a) B, C, A (b) A, C, B (c) A=B=C

Think and Explain

47. E & M induction requires change; of the intensity of a magnetic field, or of motion in a magnetic field.

48. Magnetic induction will not occur in nylon, since it has no magnetic domains. That's why electric guitars use steel strings.

49. The magnetic domains that become aligned in the iron core contribute to the overall magnetic field of the coil and therefore increase its magnetic induction.

50. The magnetic field of the iron core adds to the magnetic field of the coil, as stated in the previous answer. Greater magnetic field means greater torque on the armature.

51. Work must be done to move a current-carrying conductor in a magnetic field. This is true whether or not the current is externally produced or produced as a result of the induction that accompanies the motion of the wire in the field. It's also a matter of energy conservation. There has to be more energy input if there is more energy output.

52. While the armature of a motor spins, converting electrical energy to mechanical energy, electric current (in the opposite direction) is induced. Then a motor acts as a generator.

53. A cyclist will coast farther if the lamp is disconnected from the generator. The energy that goes into lighting the lamp is taken from the bike's kinetic energy, so the bike slows down. The work saved by not lighting the lamp will be the extra "force × distance" that lets the bike coast farther.

54. Part of the Earth's magnetic field is enclosed in the wide loop of wire imbedded in the road. If this enclosed field is somehow changed, then in accord with the law of electromagnetic induction, a pulse of current will be produced in the loop. Such a change is produced when the iron parts of a car pass over it, momentarily increasing the strength of the field. A practical application is triggering automobile traffic lights. (When small ac voltages are used in such loops, small "eddy currents" are induced in metal of any kind that passes over the loop. The magnetic fields so induced are then detected by the circuit.)

55. As in the previous answer, eddy currents induced in the metal change the magnetic field, which in turn changes the ac current in the coils and sets off an alarm.

56. The changing magnetic field of the moving tape induces a voltage in the coil. A practical application is the early models of the tape recorder.

57. In both cases the direction of the magnetic force is perpendicular to the magnetic field and the motion of charges—but with different results. In the motor effect, the magnetic force pushes the wire upward. In the generator effect, the wire is pushed downward and the magnetic force pushes electrons in a direction along the wire to produce a current.

58. Voltage is induced.

59. Agree with your friend. Any coil of wire spinning in a magnetic field that cuts through magnetic field lines is a generator.

60. In accord with Faraday's law of induction, the greater the rate of change of magnetic field in a coil or armature, the greater the induced voltage. So voltage output increases when the generator spins faster.

61. In accord with electromagnetic induction, if the magnetic field alternates in the hole of the ring, an alternating voltage will be induced in the ring. Because the ring is metal, its relatively low resistance will result in a correspondingly high alternating current. This current is evident in the heating of the ring.

62. The changing magnetic field produced when the current starts to flow induces a current in the aluminum ring. This current, in turn, generates a magnetic field that opposes the field produced by the magnet under the table. The aluminum ring becomes, momentarily, a magnet that is repelled by the hidden magnet. It is repelled, just as the aluminum ring levitates in the photo opener with Jean Curtis.

63. The electromagnet is ac, which means a continually changing magnetic field in the copper ring. This induces a current in the ring, which then becomes its own electromagnet, which is continually repelled by the large electromagnet. The force of repulsion equals the weight of the ring, producing mechanical equilibrium.

64. If the light bulb is connected to a wire loop that intercepts changing magnetic field lines from an electromagnet, voltage will be induced which can illuminate the bulb. Change is the key, so to stay lit the electromagnet should be powered with ac.

65. Since all the electric resistance in this case is merely that of the wire itself (no other external load), twice the wire length means twice the resistance. So although twice the number of loops means twice the voltage, twice-as-much resistance results in the same current.

66. Induction occurs only for a *change* in the intercepted magnetic field.
(a) The galvanometer displays a pulse when the switch in the first circuit is closed, as the current in the coil increases from zero.
(b) When the current in the first coil is steady, no current is induced in the secondary and the galvanometer reads zero.
(c) The galvanometer needle will swing in the opposite direction when the switch is opened and current falls to zero.

67. The iron core increases the magnetic field of the primary coil, as stated in the answer to question 49. The greater field means a greater magnetic field change in the primary, and a greater voltage induced in the secondary. The iron core in the secondary further increases the changing magnetic field through the secondary and further increases the secondary voltage. Furthermore, the core guides more magnetic field lines from the primary to the secondary. The effect of an iron core in the coils is the induction of appreciably more voltage in the secondary.

68. A transformer requires alternating voltage because the magnetic field in the primary winding must change if it is to induce voltage in the secondary. No change, no induction.

69. When the secondary voltage is twice the primary voltage and the secondary acts as a source of voltage for a resistive "load," the secondary current is half the value of current in the primary. This is in accord with energy conservation, or since the time intervals are the same, "power conservation." Power input = power output; or $(\text{current} \times \text{voltage})_{\text{primary}} = (\text{current} \times \text{voltage})_{\text{secondary}}$: with numerical values, $(1 \times \text{V})_{\text{primary}} = (1/2 \times 2\text{V})_{\text{secondary}}$. (The simple rule power = current × voltage is strictly valid only for dc circuits and ac circuits where current and voltage oscillate in phase. When voltage and current are out of phase, which can occur in a transformer, the net power is less than the product current × voltage. Voltage and current are then not "working together." When the secondary of a transformer is open, for example, connected to nothing, current and voltage in both the primary and the secondary are completely out of phase—that is, one is maximum when the other is zero—and no net power is delivered even though neither voltage nor current is zero.)

70. A transformer is analogous to a mechanical lever in that work is transferred from one part to another. What is multiplied in a mechanical lever is *force*, and in an electrical lever, *voltage*. In both cases, energy and power are conserved, so what is not multiplied is energy, a conservation of energy no-no!

71. A step-up transformer multiplies voltage in the secondary by having more turns in the secondary coil than in the primary coil; a step-down transformer does the opposite—less turns in the secondary, which decreases voltage in the secondary.

72. The hum heard when a transformer is operating on a 60 hertz ac line is a 60 hertz forced vibration of the iron slabs in the transformer core as their magnetic polarities alternate. The hum is greater if any other mechanical parts are set into vibration.

73. The name of the game with E&M is *change*. No change, no induction. Alternating current changes direction, normally at 60 Hz.

74. High efficiency requires that the maximum number of magnetic field lines produced in the primary are intercepted by the secondary. The core guides the lines from the primary through the secondary. Otherwise some of the magnetic field generated by the primary would go into heating metal parts of the transformer instead of powering the secondary circuit.

75. A physical space is between the two. They are linked, however, by changing magnetic fields—the same in each coil.

76. The voltage impressed across the lamp is 120 V and the current through it is 0.1 A. We see that the first transformer steps the voltage down to 12 V and the second one steps it back up to 120 V. The current in the secondary of the second transformer, which is the same as the current in the bulb, is one-tenth of the current in the primary, or 0.1 A.

77. Oops! This is a dc circuit. Unless there is a changing current in the primary, no induction takes place. No voltage and no current are induced in the meter.

78. By symmetry, the voltage and current for both primary and secondary are the same. So 12 V is impressed on the meter, with a current of 1 A ac.

79. No, no, no, a thousand times no! No device can step up energy. This principle is at the heart of physics. Energy cannot be created or destroyed.

80. The moving magnet will induce a current in the loop. This current produces a field that tends to repel the magnet as it approaches and attract it as it leaves, slowing it in its flight. From an energy point of view, the energy that the coil transfers to the resistor is equal to the loss of kinetic energy of the magnet.

81. The source of an electromagnetic wave is an oscillating electric charge.

82. Waving it changes the "flux" of the Earth's magnetic field in the coil, which induces voltage and hence current. You can think of the flux as the number of field lines that thread through the coil. This depends on the orientation of the coil, even in a constant field.

83. The incident radio wave causes conduction electrons in the antenna to oscillate. This oscillating charge (an oscillating current) provides the signal that feeds the radio.

84. The frequencies are the same.

85. Agree with your friend, for light is electromagnetic radiation having a frequency that matches the frequency to which our eyes are sensitive.

86. Electromagnetic waves depend on mutual field regeneration. If the induced electric fields did not in turn induce magnetic fields and pass energy to them, the energy would be localized rather than "waved" into space. Electromagnetic waves would not exist.

Think and Discuss

87. Copper wires were not insulated in Henry's time. A coil of non-insulated wires touching one another would comprise a short circuit. Silk was used to insulate the wires so current would flow along the wires in the coil rather than across the loops touching one another.

88. When the ground shakes, inertia of the suspended massive magnet tends to resist such shaking. But the coils of wire are fixed to the Earth and shake relative to the magnet. Motion of the magnet within conducting loops induces a current, which depends on the strength of the earthquake. So the law of inertia and the law of electromagnetic induction underlie the operation of this device.

89. Two things occur in the windings of the electric motor driving a saw. Current input causes them to turn and you have a motor. But motion of windings in the magnetic field of the motor also make them a generator. The net current in the motor is the input current minus the generated output current, which is opposite in direction to the input current. You pay the power company for the net current. When the motor jams, the net current is increased because of the absence of generated current. This can burn the windings of the saw!

90. In a power line, the high voltage is between one wire and another, not from one end of a given wire to the other end. The voltage difference between one end of the wire and the other is actually small, corresponding to the small current in the wire. The voltage difference *between the wires* multiplied by the current gives the power transmitted to the load. The voltage difference *between one end of a wire and the other* multiplied by the current gives the (much smaller) power dissipated in the wire. So, in applying Ohm's law, it's important that the voltage and current are applied to the same part of the circuit.

91. As the magnet falls, it induces current that circles in the conducting pipe and is accompanied by its own magnetic field. The moving magnet is slowed by interaction with this induced field.

92. Slowness of fall is due to interaction of the magnetic field of the falling magnet with the field induced in the conducting tube. No conduction, as with a cardboard tube, means no induced field and no slowness of fall.

93. Motion of conducting sheets through a magnetic field induces swirling currents (eddy currents) with fields that interact with the magnet and slow motion. Such doesn't occur in non-conducting cardboard.

94. Induced currents in the bar are accompanied by their own magnetic fields, which interact with the magnet and slow motion.

95. A voltage difference is induced across the wings of a moving airplane. This produces a momentary current and charge builds up on the wing tips to create a voltage difference that counteracts the induced voltage difference. So charge is pulled equally in both directions and doesn't move.

96. Such a scheme violates both the 1st and 2nd laws of thermodynamics. Because of inherent inefficiencies, the generator will produce less electricity than is used by the adjoining motor to power the generator. A transformer will step up voltage at the expense of current, or current at the expense of voltage, but it will not step up both simultaneously—that is, a transformer cannot step up energy or power. Like all practical systems, more energy is put in than is supplied for useful purposes.