L 28 Electricity and Magnetism [6]

- magnetism
- Faraday's Law of Electromagnetic Induction
  - induced currents
  - electric generator
  - eddy currents
- Electromagnetic Waves (Maxwell & Hertz)

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Basic facts of Magnetism

- Oersted discovered that a compass needle responded to the a current in a loop of wire
- Ampere deduced the law describing how a magnetic field is produced by the current in a wire
- *magnetic field lines are always closed loops* – no isolated magnetic poles; magnets always have a north and south pole
- permanent magnets: the currents are *atomic currents* – due to electrons spinning in atoms - these currents are always there
- electromagnets: currents in wires produce magnetic fields

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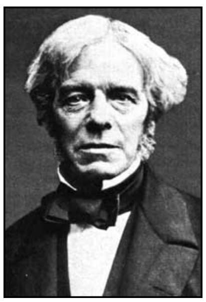
Faraday's Law of Electromagnetic Induction

- Faraday thought that if currents could produce magnetic fields, (Oersted, Ampere) magnetic fields might produce currents
- He was correct, with one important qualification: the magnetic field must be *changing* in some way to produce a current
- the phenomenon that a changing magnetic field can produce a current is called electromagnetic induction



Michael Faraday (1791-1867)

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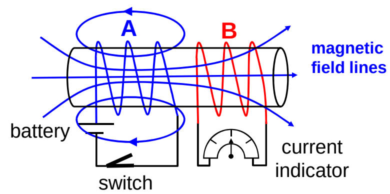
Induced currents (a)



- When a current is turned on or off in coil A, a magnetic field is produced which also passes through coil B.
- A current then **briefly** appears in coil B
- The current in coil B is called an **induced current.**
- The current in B is only present when the current in A is turned on or off, that is, when the current in A is *changing*

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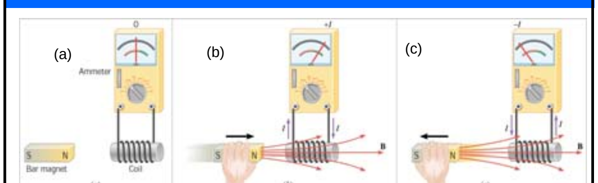
Induced currents (b)



a) No current is induced if the magnet is stationary.
b) When the magnet is pushed toward the coil or pulled away from it, an induced current appears in the coil.
c) The induced current only appears when the magnet is being moved

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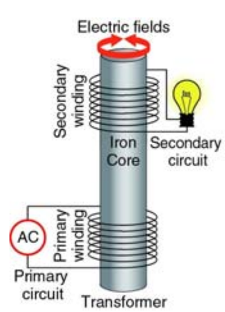
Induced currents (c)



- If an AC (time varying) current is used in the primary circuit, a current is induced in the secondary windings.
- If the current in the primary windings were DC, there would be NO induced current in the secondary circuit.
- Levitated coil demo

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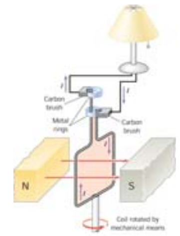
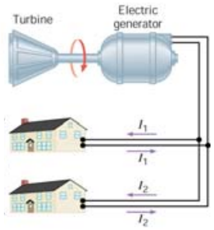
electric generators





When a coil is rotated in a magnetic field, an induced current appears in it. This is how electricity is generated. Some external source of energy is needed to rotate the turbine which turns the coil.

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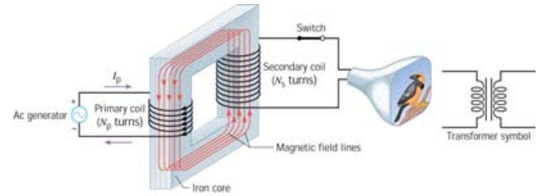
The transformer



The voltage on the secondary depends on the number of turns on the primary and secondary.

Step-up → the secondary has more turns than the primary
Step-down → the secondary has less turns than the primary

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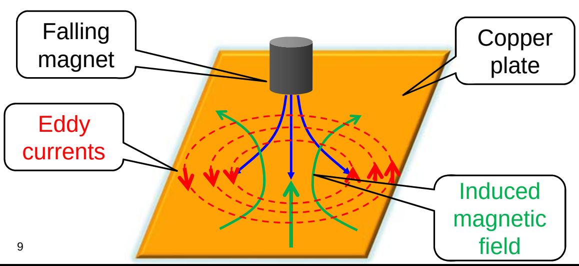
Eddy currents

- Eddy currents are induced in conductors if time-varying magnetic fields are present
- As the magnet falls the magnetic field strength at the plate increases



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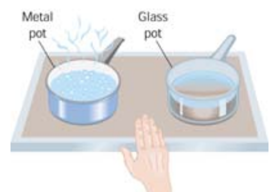
Eddy currents → application

An induction stove uses
eddy currents to cook food



Only the metal pot gets hot, not the glass pot or the stove.

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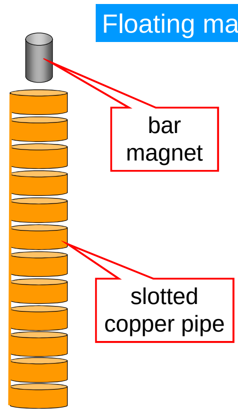
Floating magnet – induced currents



- As the magnet falls, it induces currents in the copper pipe known as eddy currents.
- These eddy currents produce a magnetic field that *opposes* the field of the falling magnet, so the magnet does not accelerate but descends slowly.

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The Laws of Electricity and Magnetism

- Laws of electricity
  - electric charges produce *electric* fields (Coulomb)
  - electric fields begin and end on charges
- Laws of magnetism
  - currents produce *magnetic* fields (Ampere)
  - magnetic field lines are closed loops
  - a changing magnetic field can produce a current (*induced currents*) (Faraday)
  - A changing electric field can produce a magnetic field (Maxwell)

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ELECTROMAGNETIC (EM) WAVES

Faraday laid the groundwork with his discovery of electromagnetic induction

EM WAVES ⬇ LIGHT

James Clerk Maxwell in 1865 predicted theoretically that EM waves should exist

Heinrich Hertz showed experimentally in 1886 that EM waves exist

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Electromagnetic (EM) waves

- Mechanical wave: a disturbance that propagates in a *medium* (eg, water, strings, air)
- An electromagnetic wave is a combination of electric and magnetic fields that oscillate together in space (*no medium*) and time in a synchronous manner, and propagate at the speed of light 3×10^8 m/s or 186,000 miles/s.
- EM waves include radio, microwaves, x-rays, light waves, thermal waves gamma rays

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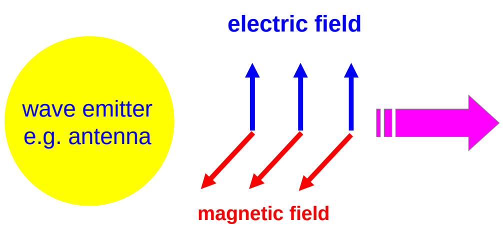
the generation of an electromagnetic wave



The time varying electric field generated the time varying magnetic field which generates the time varying electric field and so on and so on . . . .

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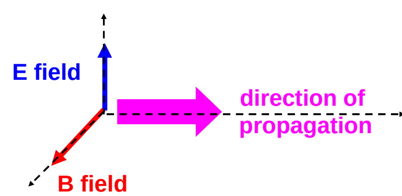
EM waves: transverse

- the electromagnetic wave is a *transverse wave*, the electric and magnetic fields oscillate in the direction perpendicular to the direction of propagation



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Electromagnetic waves

- the EM wave propagates because the electric field recreates the magnetic field and the magnetic field recreates the electric field
- an oscillating voltage applied to the antenna makes the charges in the antenna vibrate up and down sending out a synchronized pattern of electric and magnetic fields
- *an **electromagnetic** wave must have both an electric and magnetic field component*

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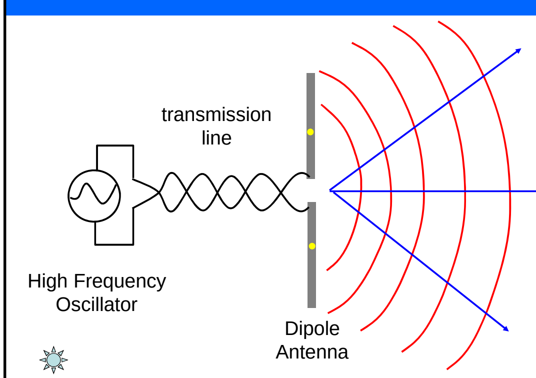
How radio waves are produced



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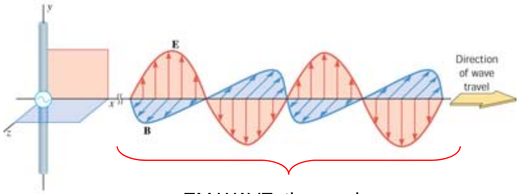
Electromagnetic Waves



Antenna: emits waves

EM WAVE: time and space varying electric and magnetic fields moving through space at the speed of light, c = 3 x 10^8 m/s = 186,000 miles/sec

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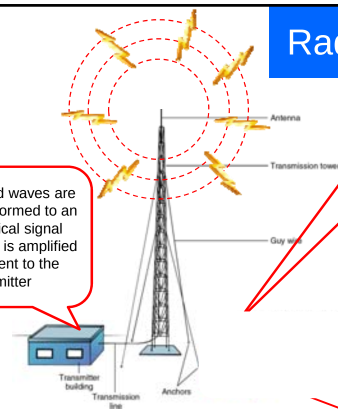
Radio antenna



Sound waves are transformed to an electrical signal which is amplified and sent to the transmitter

the EM wave causes the electrons in the receiving antenna to oscillate at the same frequency

the amplifier converts the electrical signal to sound waves

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The periodic wave relation applies to electromagnetic waves

- the periodic wave relation: $c = \lambda f$
  speed = wavelength × frequency
  applies to electromagnetic waves.
- the speed **c** is roughly 300,000,000 m/s
- for example, the wavelength of a 1 MHZ radio wave is:

$$= \frac{300,000,000}{1,000,000} = 300\ m$$

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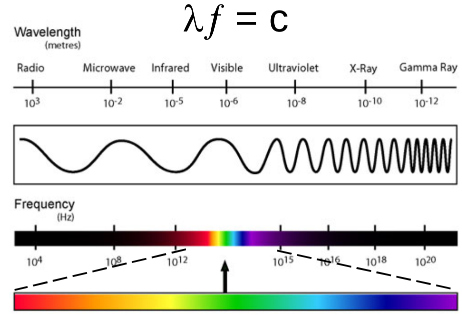
Electromagnetic spectrum

λf = c



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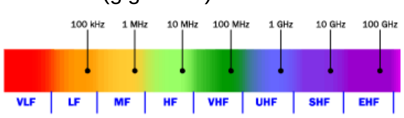
Common frequency bands

- 1 vibration per second = 1 Hertz (Hz)
- 1 KHz (kilohertz) = 10^3 Hz
- 1 MHz (megahertz) = 10^6 Hz
- 1 GHz (gigahertz) = 10^9 Hz



- **AM radio**: 535 KHz – 1.7 MHz
- **FM radio**: 88 – 108 MHz
- **GPS**: 1.227 and 1.575 GHz
- **Cell phones**: 824 MHz – 2 GHz

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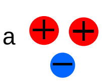
Microwaves

- are in the frequency range of a few billion Hz or wavelengths of about several cm (about the same range as radar → the "Radarange"
- **How do microwaves heat water?**
- Remember that the water molecule has a positive end and a negative end.



- The electric field of the microwave grabs onto these charges and shakes them violently a few billion times each second
- all this shaking energizes the molecules making the water hotter and hotter.

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