Chapter 8: E & M (Electricity & Magnetism or Electromagnetism)

Charge *conservation*&*quantization* (review from last class)
Electric current & circuits
Resistance & Ohm's Law
Concept of ***FIELD*** (electric/magnetic/gravitational)
Magnetism – only a few examples

Another crucial conservation law:

Electric charge is conserved! – Charges can be moved, but no **net** charge (positive minus negative) is ever created or destroyed in a process….and quantized! – integer multiples of Q_e or Q_p

Examples from high-energy/particle physics:

1) High energy "photons" (chunks of light, more in ch. 12) interact with matter: γ ("gamma", the photon, charge 0) $\rightarrow e^- + e^+$ (e^+ = "positron", anti-particle of the electron, opposite charge)

2) p + p → anti-p + p + p + p (because of charge conservation a (p – anti-p) pair has to be produced, costing lots of energy!)

Quiz # 60: Suppose you had enough energy in the incident particles and can satisfy energy & momentum conservation, could the following reaction happen: $e^- + e^+ \rightarrow$ p(roton) + n(eutron) ?

(a) no (b) yes

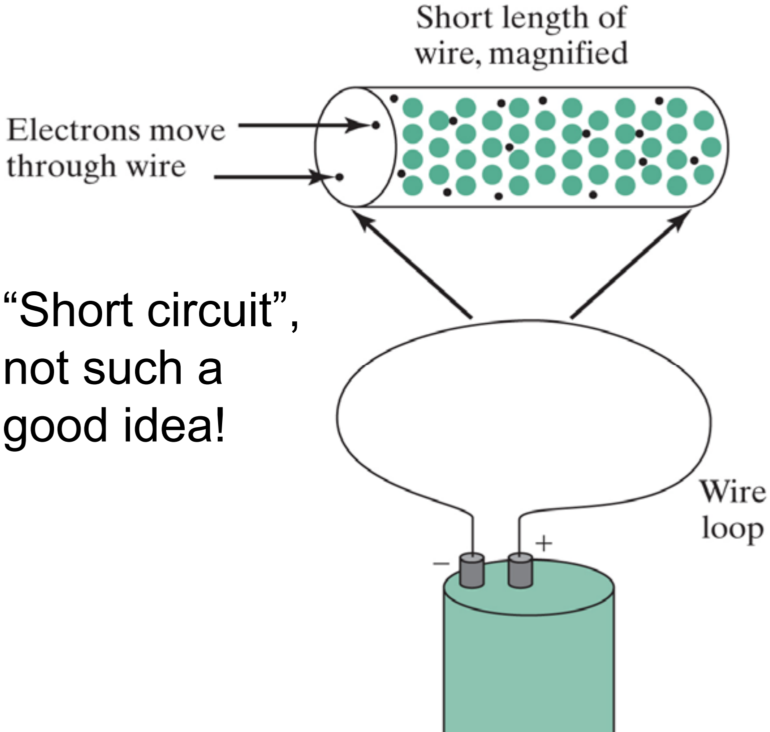
What about $e^- + e^+ \rightarrow$ p + n + anti-p ? (Apart from charge conservation there is another, particle-physics problem above……)

Electric Circuits:

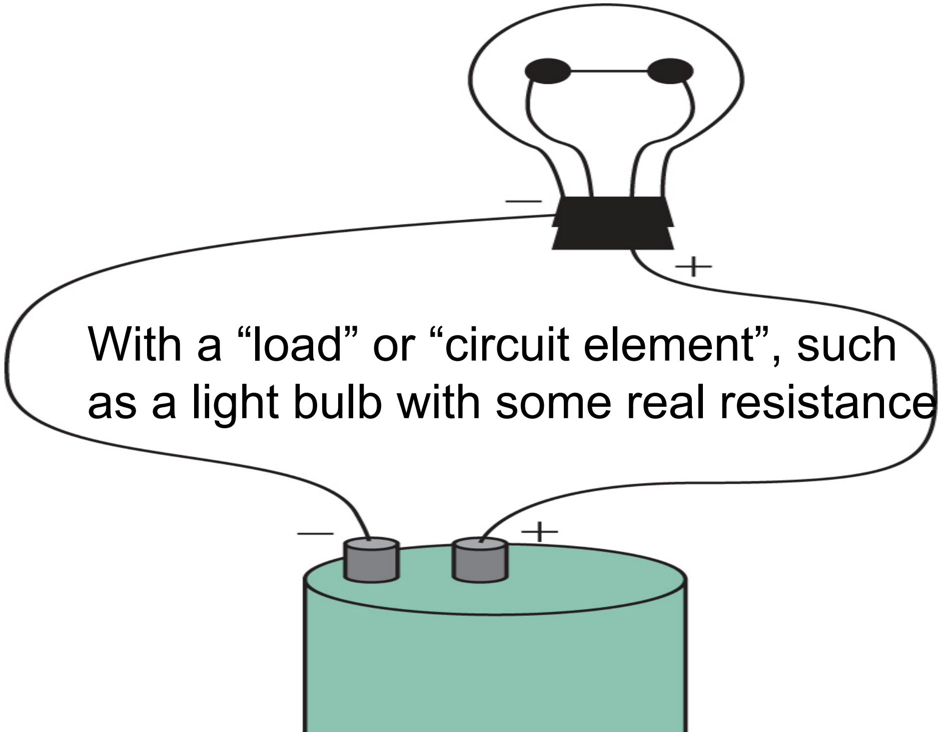
In electrical conductors (as opposed to “semi-conductors” and insulators), for instance almost all metals, so-called conduction electrons can move fairly easily →*electrical* ***current***, measured in A(mps) = C(oulomb) / s(econd).

Typically only 1-2 electrons per atom, and with surprisingly low *drift velocity* of only ~ 1 mm/second!

Reason: electrical ***resistance*** from constantly bumping into atoms.



“Short circuit”, not such a good idea!



With a “load” or “circuit element”, such as a light bulb with some real resistance.

Battery in simple terms: a device using $E_{chemical}$ to move e^- from + terminal to – terminal, *against* $F_{electric}$! Analogy: moving an object uphill. At the negative terminal the e^- therefore possess $E_{electrical}$. E conservation, remember!

e^- can now do work in an external circuit by "falling" back to the + terminal, and the process begins over….until $E_{chemical}$ in the battery is exhausted, i.e. the battery is empty or discharged.

How much E? Represented by ***voltage***, measured in V(olts) = J(oules) / C(oulomb).

Note:

1) Is a piece of conductor with current flowing through it electrically charged?

A: NO! Why not?

2) The conduction e^- move essentially immediately (all of them!) once the circuit is closed, albeit with their very low drift velocity. Rather remarkable – "speed of light" involved, more on that later.

C. E. 25 (A: no) & 26/27/29: *thin* filament is like a thin pipe or garden hose – e^- are forced to move faster → more violent e^- - atom collisions, resulting in more $E_{thermal}$, i.e. filament glows & radiates. Also note: *thinner* wire → *higher* resistance! (makes sense?)

Quiz # 61: In a circuit consisting of a battery, wire, and a light bulb, the E transformations in the battery and in the light bulb are, respectively

(a) $E_{chemical} \rightarrow E_{electrical}$ and $E_{thermal} \rightarrow E_{electrical}$
(b) $E_{electrical} \rightarrow E_{chemical}$ and $E_{thermal} \rightarrow E_{electrical}$
(c) $E_{chemical} \rightarrow E_{electrical}$ and $E_{electrical} \rightarrow E_{thermal} + E_{radiation}$
(d) $E_{electrical} \rightarrow E_{chemical}$ and $E_{electrical} \rightarrow E_{thermal} + E_{radiation}$
(e) $E_{thermal} \rightarrow E_{electrical}$ and $E_{electrical} \rightarrow E_{thermal} + E_{radiation}$

AC vs. **DC**: not covered in any detail, but you should know the fundamental difference. In the US: 110V, 60 cycles/second
AC has generation & transmission advantages (transformers, high voltages lines across the country)

Ohm’s Law (not a fundamental law à la Newton or our conservation laws, i.e. not every material is “ohmic” in nature and obeys this law.):

Nevertheless, for many materials one finds:
V(oltage) proportional to current I, or V = R(esistance) × I
Unit for R: ohm (Ω) = Volt / Amp (Note: 1 Ω is a fairly low R)

Ohm’s law makes intuitive sense - for instance that I = V / R

C.E. 27 : Thicker filament means lower R, and therefore larger I.

Problem 14: 120 Volts, 6 ohms → I = V / R = 120 Volts / 6 ohms = 20 amps – that’s a lot of current!

Quiz # 62: I = 0.5 amp runs through a lamp with R = 200 Ω. The voltage across the lamp is
(a) 200 V (b) 80 V (c) 400 V (d) none of these

Important concept of a **Field**, represented by “field lines”:
(let’s not make it more magical than it is!) …… *demos*!

It’s a **representation of a (fundamental) force**, incl. long-range, non-contact forces such as gravity, electric & magnetic forces. Think of it as a disturbance or a stress in space.

Force by A on B occurs because A causes this stress, i.e. sets up this field, and B feels it.

→*A field exists at a point P whenever an object would feel a force at that point P.*

Important: The above field exists at P even if there is no object there!
(Of course, this field is due to some other object somewhere else.)

Is there a “gravitational field” in this room? How do you know?
Everywhere in this room? Outside the room?

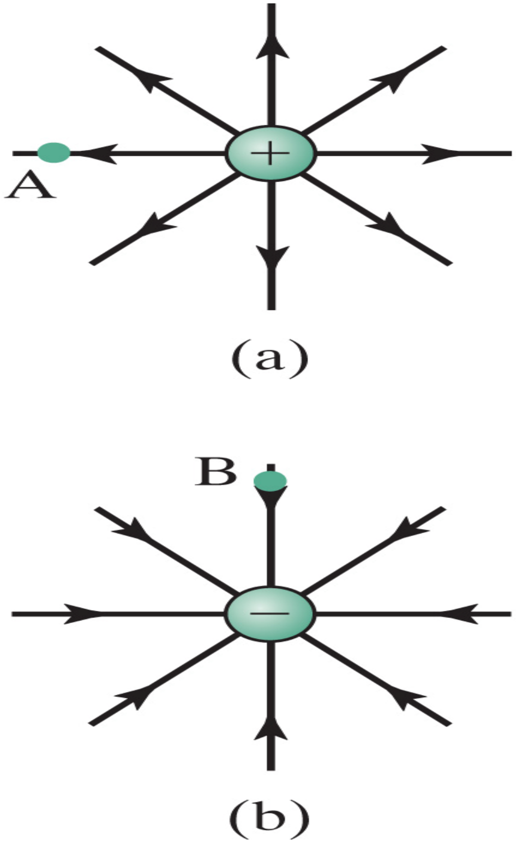
A(ny) mass sets up a gravitational field, and feels forces due to the gravitational field of other masses.

An(y) electric charge sets up an electric field, and feels……..

A(ny) moving electric charge sets up a magnetic field, and feels…

Visualization of fields via “field lines”, electric case:

→ Direction: taken as the force direction a + charge would feel.



(a)

(b)

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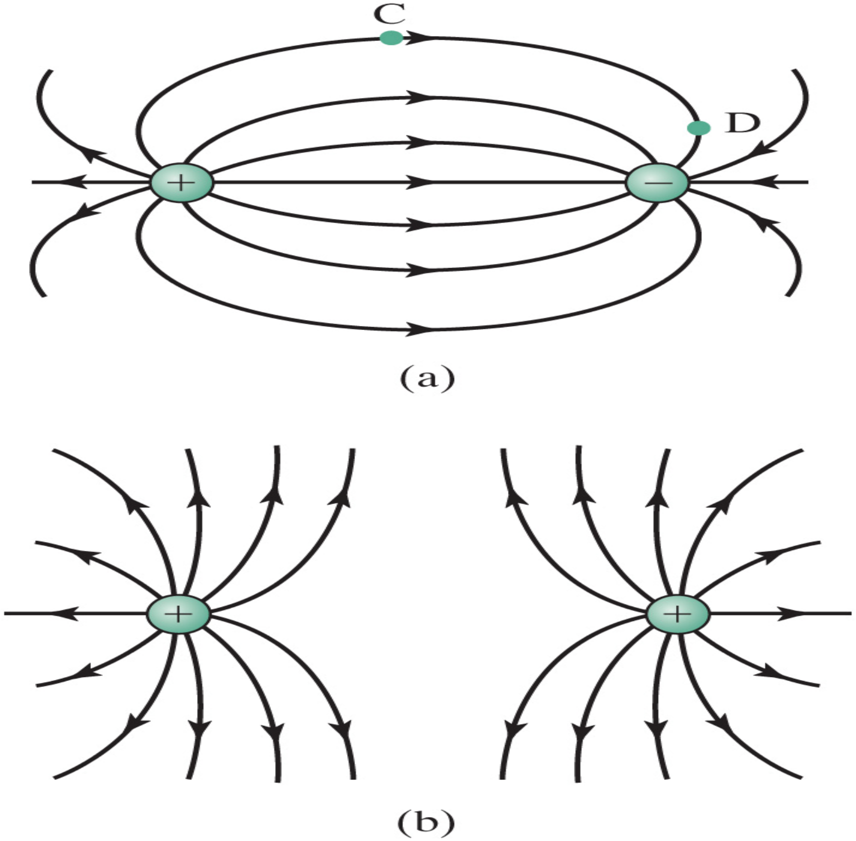
Guess: how might the strength of the force be represented pictorially?

Concept checks 7 – 9 !



(a)

(b)

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C.E. 31: No, field not made of atoms. Same for gravitational field.

Something to keep in mind (C.E. 32): there ***is*** energy associated with a field.

Quiz # 63: How would a proton's motion differ from an electron's at the same point in the same electric field? Both are at rest initially.

(a) They would both remain at rest.

(b) They would both accelerate at the same rate and in the same direction.

(c) They would both accelerate at the same rate, but in opposite directions.

(d) Electron's acceleration would be larger, and they'd move in opposite directions.

(e) Proton's acceleration would be larger, and they'd move in the same direction.

Hint: don't forget that the magnitude of F_{electric} on a particle is proportional to the magnitude of its electric charge.

Quiz # 64: How does the electrostatic force between two hydrogen nuclei placed a certain distance apart compare with the force between two helium (atomic # 2) nuclei placed twice as far apart?

(a) It’s the same.
(b) For hydrogen twice as large as for helium.
(c) For helium twice as large as for hydrogen.
(d) For helium four times as large as for hydrogen.
(e) For hydrogen four times as large as for helium.