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21 Electric Fields

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Objectives

- Calculate el. force between charges
- electric field and field strength
- electric potential, p.d.
- application: the electron gun

Some fundamental facts

- Objects are usually uncharged ('neutral').
- Two types of charges: positive / negative
  - Like charges repel.
  - Opposite charges attract.
- Two classes of material: conductors (free electrons) and insulators (no free electrons)
  special case: semiconductors (few free el.)

How to charge an object?

- If an object is uncharged that means...
  # of protons = # of electrons
  (because $q_{prot} = -q_{elect}$ = elem. charge)

- By rubbing two materials, electrons are torn off one surface (=> pos. charged), stick to the other surface (=> neg. charged).

image from: Hewitt P.: Concept. Physics, Pearson Intl, p. 417

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How to charge an object? (2)

- Another way is so called **electrostatic induction** (in german: Influenz).
- Two experiments: take notes...

Coulomb's Law

- Charles Coulomb discovered in 1785 that the force between two charged spheres is...
  - proportional to each of the charges and
  - inversely proportional to the square of the distance between the two (**closeness wins**).

image source: http://en.wikipedia.org/wiki/Image:Coulomb.jpg, 25.5.08

Coulomb's Law (2)

- Applies to point charges and charged spheres only!
- k = prop. constant
- ε_0 = permittivity of free space (or air)

$$F = k \times \frac{Q_1 Q_2}{r^2}$$

$$k = 9 \times 10^9 \ \frac{\mathrm{Nm^2}}{\mathrm{C^2}}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

Another inverse square law

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Comparison between

Newton: Gravity	**Coulomb: Charges**
force "felt" by mass	"felt" by charge
$F \propto$ size of masses	$F \propto$ size of charges
F inversely proportional to distance squared	
one type of mass => always attractive	**two** types of charges => attract. or repulsive
very weak force	very strong force

Coulomb: An example

- Suppose you were able to **split one gram of salt into** sodium and chloride **ions** and to **put them 1 metre apart**.
  Calculate the force between these two charges!

Electric field strength *E*

- el. field = region where charges 'feel' a force
- "The el. field strength at a point is the force per coulomb exerted on a positive charge placed at that point in the field."
- El. field strength = force per charge
- $E = F / Q$, [E] = N/C = V/m

Electric fields

- el. field = region where charges 'feel' a force
- How to visualize the shape of electric fields?
  - Vectors
  - Field lines

How to draw f.l. patterns

- Field lines always extend from (+) to (-).
  (Infinity can act as (+) or (-), if needed.)
- Arrows on the f.l. indicate direction.
- Spacing of the lines / number of field lines indicate the strength of the field.
- F.l. never have corners, they never cross each other.
- F.l. meet the surface of conducting objects always at right angles.

Conclusions

- Electric fields **cannot** be shielded using **insulators**!
- El. fields can only be **shielded** using a **metal cage**, so called **Faraday cage**.
- BBC video about lightning...

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Video about lightning

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Conclusions (cont'd)

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- El. fields are particularly strong at edges ("point effect").
  => preferred place for field emission, coronal discharge
- **St. Elmo's fire**: glowing tails/noses/masts when aircraft/ships approach a storm

Two special cases

- Uniform field, between charged parallel plates

- V: p.d. between the plates
  d: distance " " "

$$E = \frac{F}{q} = \frac{V}{d}$$

- Field of a point charge or a sphere w. charge Q

- Radial field

- (Inside the sphere $E = 0$)

$$E = \frac{F}{q} = k \times \frac{Q \not{q}}{r^2 \not{q}}$$

example:
Van de Graaff generator

- **rule of thumb: 3 kV/mm** (or 3 MV/m) is needed to ignite a spark discharge
- How much charge is stored on the dome of the VdGg?

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example: Millikan's oil-drop experiment

- performed in 1910, he won the Nobel prize in 1923
- first direct measurement of the electric charge of a single electron
- oil drops held in suspense by an el. field

© Picture: Nobel Lectures, Physics 1922-1941, Elsevier Publishing Company, Amsterdam, 1965

Electric potential

- Move a charge in an electric field by exerting a force on it.
- comparison between gravitational and electric fields
- on the blackboard...

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Electric potential /2

- Move a charge using a force => work done => charge has gained pot. energy
- (Do you remember?: field = force **per charge**, property of space around a charge!)
- New quantity: pot. energy **per charge...**
- ... is a property of space as well!

Electric potential /3

- energy/charge = electric potential V
- **V at any point in an el. field is the pot. energy that each coulomb of pos. charge would have if placed in the field.**
- Units: [V] = joules/coulomb = volts (V)

Earthing

- to earth an object = to connect it with the Earth using a conductor
- We often use the Earth as a reference point => **Earth has zero potential**.
- In electrostatics, all points of a conducting surface are at the same potential. Why?

Potential difference

- work done to get from point A to point B = energy at B - energy at A =>
- p.d. = energy transferred per charge when moving from A to B
- $V = W / Q, W = V \times Q$

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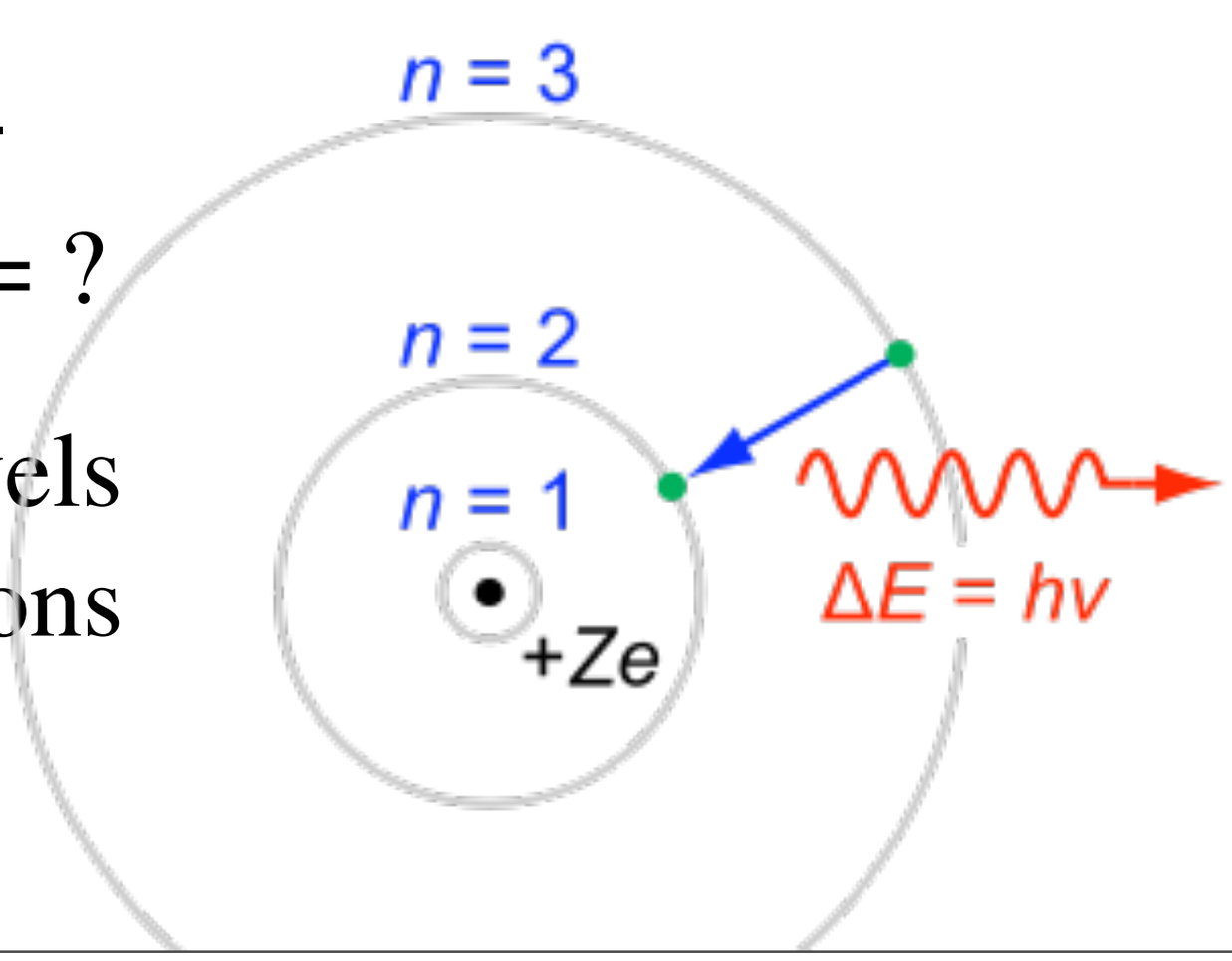
Equipotential surfaces (e.p.s.)

- All points with the same potential lie on an e.p.s.
- short name: an equipotential (w'out surface)
- like the contour lines on a map
- always at a right angle to the field lines.

Application: The hydrogen atom

- The electron "circles" the nucleus.
- V at 0.053 nm from the nucleus = 13.6 V
- Energy needed to remove e^-: $W = V \times Q = ?$
- Changing energy levels => emission of photons



Application: Electron beam

- electron gun, cathode ray tube (CRT)
- used in television sets and computer screens (if it's not flat screen)
- used in oscilloscopes
- proceed on the blackboard...