Background repetition – Electricity and Circuits

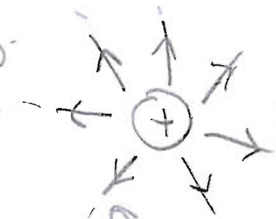
It's all about **CHARGE**
laddning

Symbol usually Q or q
SI unit coulomb
$1C \simeq 6 \times 10^{18}$ elementary charges

Charge can be positive or negative.
It describes participation of the matter in electric FORCES.
krafter

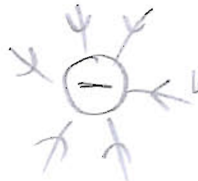
Electric **FIELD** is a way to describe the force that a positive charge would experience at different points in space, due to other charges that are causing the field.

E.g.



another positive charge is pushed away

or



a positive charge is pulled towards (or a negative charge is pushed away)

electric field (a vector)
Symbol E
SI unit volt per metre
V/m

The electric fields caused by fixed charges are "conservative", like gravitational fields caused by masses. Around any closed path, the total energy given to a charge by the field force is zero.

So we can define a **POTENTIAL** that describes the energy needed to move a unit charge from a reference point to some point we're considering

symbol often V or φ
SI unit volt, V
equivalent to joule/coulomb

Between two points, the DIFFERENCE of POTENTIAL defines the energy needed to move charges between them. This conveniently does not depend on what "reference" (zero point) was used for defining the potentials.

A movement of charge is a CURRENT
ström

Symbol I or i
SI unit ampère, A
equivalent to $\frac{\text{coulomb}}{\text{second}}$

It is defined by the rate of movement of charge (charge/time) across some defined boundary.
gräns/yta

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i.e. broadest

In the general case of physics and electrical engineering, we work with field problems in 3D space and in time.

consider some physical situation ⇓ then define relevant quantities such as:

a motor with copper coils, iron frame, plastic insulation

the world's ionosphere with currents causing "norrskenet"

a battery and lamp

function of position and time

rho

$\rho(x, y, z, t)$ charge density (C/m^3)

$\bar{E}(x, y, z, t)$ electric field (V/m)

$\bar{J}(x, y, z, t)$ current density (A/m^2)

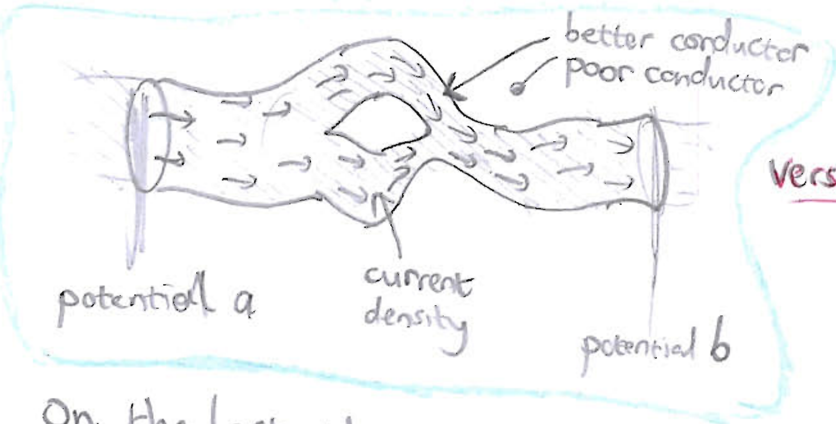
and magnetic field $B(x, y, z, t)$
and material properties.

.... then solve lots of equations.

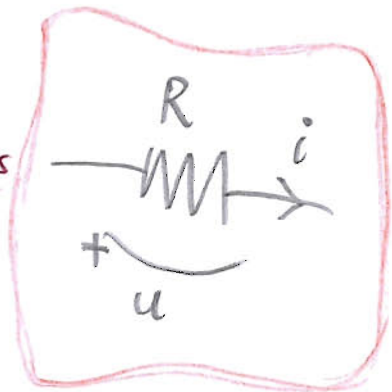
COMPLICATED !!

CIRCUITS are a simplification of fields

They combine a lot of spatial detail.
(i.e. lose!)



Versus



On the left we see an object where a current travels through a conductive material, which might have different conductivity at different points!
In many cases we do not care about the exact distribution of current or potential inside the object, but just the total current passing through, and how this is related to the difference in potential between the ends.
That might be the case if the object is a RESISTOR in an electronic circuit, or a WIRE carrying current in a building.

⇒ Then, the CIRCUIT MODEL is sufficient.
It is shown on the right.
Instead of a set of vector and scalar fields in space, we have two simple quantities:

total current i

voltage u
(difference of potential)

If the material is suitably "linear" as a conductor, then there's a simple relation $\frac{u}{i} = R$ constant

MUCH SIMPLER than a general field model.

There are other simplifications involved in a circuit model.

E.g. • changes in potential (circuit potential) may be due to:

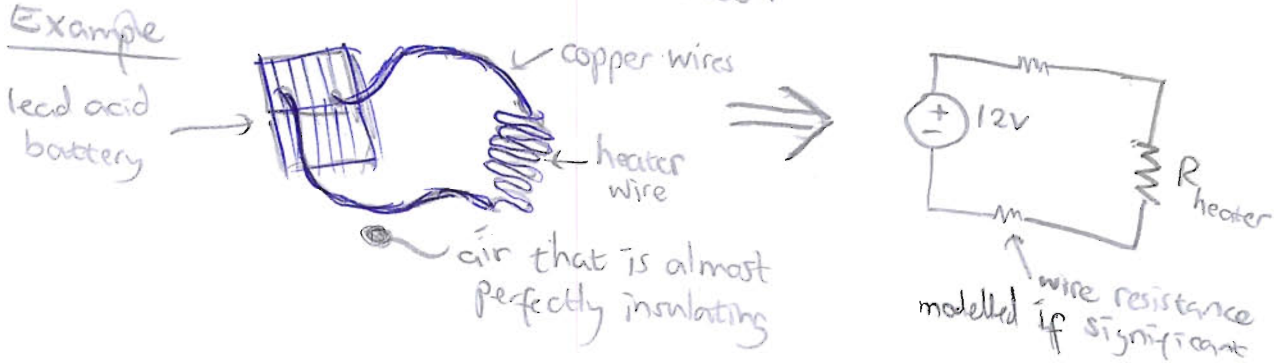
- Changes of electrostatic potential
- magnetic forces on moving charges
- Changing magnetic field
- diffusion potential of chemicals (battery)
- energy loss of moving charges
  - electrons in metal
  - ions in liquid or gas
  "collisions"
- ...

• and currents (in circuit model) may be due to charge movement or ...

> But we don't need to go into this now!
> **We'll learn to solve ABSTRACT, IDEAL, CIRCUITS.**
> Applications come in later courses.

- **Sometimes** a physical system is very obviously "mapped" to an abstract circuit model, and very good solutions can be obtained.

<u>Example</u>



- **Sometimes it's not so obvious!**

In some cases we need general FIELD SOLUTIONS.

In others we choose to think hard to make adequate CIRCUIT models

In circuit models the main quantities are:
(storheter)

voltage u
spänning

and current i
ström

From these we can define further quantities such as potential, charge, power (effekt), energy, resistance (motstånd), when useful.

We study linear circuits in this course.
A linear system is one where the currents and voltages caused by the various sources that "drive" the circuit are directly proportional to the source strength, and influences of different sources can be treated separately (superposition). We come to this later!

A simple example of ~~non~~linearity is an incandescent lamp!
glödlampa.
When it is white hot, e.g. 3000 K its resistance is several times more than at room temperature.
Putting more current makes it hotter → more resistance.
So it is not true that $\frac{u}{i} = R = \text{constant}$ for the lamp.
If we halve the voltage, we do not halve the current.
It is not a linear component.
But sometimes we anyway model it as simple R!

Physical quantities — more on this in a guest lecture

To describe a physical quantity (storhet) we can use a:

unit (describing an agreed amount of voltage, current or whatever)

and a

numeric value (number showing how much bigger our quantity is than the unit)

The number, unit pair defines the quantity.

Example: 20 V a voltage 20 times as big as the unit "volt"

12 A etc.

60 Ω

In our equations we often use a symbol to represent a physical quantity, for example a voltage U, or a current I or resistance R.

In symbolic calculations we say this symbol represents the whole quantity. E.g. $U = 90\,V$ or equivalently $U = 0.09\,kV$. Then we can state that a voltage is U, without needing to write "$U\,V$" (volts) — that would be wrong as it would mean e.g. $(90\,V)\,V$ $(= 90\,V^2)$!

(That's different from classic school or industrial habits, where symbols represent the numbers (pure number) we would type on a calculator.)

Dimensional checking

DIMENSION describes the type of a quantity, e.g. $\left\{ \begin{array}{l} \text{voltage} \\ \text{charge} \\ \text{current} \\ \text{force} \end{array} \right.$

A UNIT is a chosen size of quantity of a particular dimension.

For example, one volt (1 V) is a standardised amount of voltage.

A purist may prefer to respect the difference in generality between unit and dimension.

But we're so used to assuming SI units, that we can tolerate talking about "has dimension "ampère"", or "has dimension $[C][s]^{-1}$"

coulomb per second

A number without dimension is "dimensionless": often it's a ratio like $\frac{i_1}{i_2} = \frac{2[A]}{4[A]} = \frac{1}{2}$.
(pure number)

Equations with physical quantities follow some rules:

- $\{+, -, =\}$ are only applied to similar quantities
  - $i_1 + 2i_2$ ok currents (same dimension)
  - $1 + u$ NO pure number and voltage
  - $u + i$ NO voltage and current

- $\{\times, \div\}$ can create different types of quantities
  (or $\cdot$, $/$)

  $\frac{u}{i} \Rightarrow$ resistance

  $\frac{P}{i} \Rightarrow$ voltage

  hence eg. $iR = u$ ok; $\cancel{uR = i}$ NO, if u: voltage, i: current, R: resistance

Dimensional checking ensures these rules are followed.

dimensional error (dim.fel) $\Rightarrow$ error in equation

no dimensional error $\Rightarrow$ can still be other errors in equation

Eg. dimensional check:

ok — both are voltage (potential is "voltage to a reference")

$$i_1 = \frac{V_1 - u_x}{1 + \frac{R_1}{R_2} + R_3}$$

Problem ⇒

this expression needs to be a resistance:

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

What is it?

$$1 + \frac{R_1}{R_2} + R_3$$

1: pure number

$\frac{R_1}{R_2}$: pure number

R_3: resistance

Can't add the number to a resistance

⇒ so something seems wrong in the derivation of the $1 + \frac{R_1}{R_2}$ part

On the other hand, this would be ok:

$$i_1 = \frac{V_1 - u_x}{\left(1 + \frac{R_1}{R_2}\right) R_3}$$

$$[A] = \frac{[V] - [V]}{\left(1 + \frac{[\Omega]}{[\Omega]}\right) \cdot [\Omega]}$$

$$\Rightarrow [A] = \frac{[V]}{[\Omega]}$$