

OUTLINE

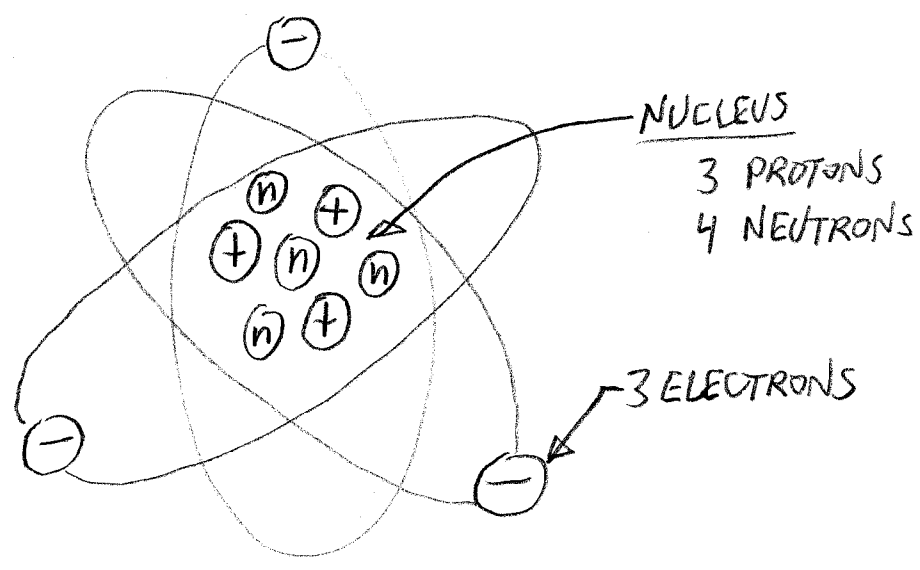
TODAY'S TOPIC: CHARGE, VOLTAGE, CURRENT, RESISTANCE

- ELECTRIC CHARGE
- ELECTROSTATIC FORCE
- ELECTRIC FIELDS
- POTENTIAL (VOLTAGE)
- CURRENT
- RESISTANCE AND OHM'S LAW
- POWER

ELECTRIC CHARGE

MATTER IS STRUCTURED BY ELECTRICALLY CHARGED PARTICLES.

CARTOON OF A LITHIUM ATOM (Li, Z=3, 7amu, VALENCE +1)



THE SI UNIT OF CHARGE IS THE COULOMB (C)

PARTICLES IN NATURE CARRY CHARGE IN PACKETS OF SIZE e ,

$$e = 1.6 \times 10^{-19} \text{ C}$$

ELECTRON: $-e$

PROTON: $+e$

(WE WILL USE SI UNITS THROUGHOUT THIS COURSE.)

Q: HOW MANY ELECTRONS IN 1 COULOMB?

ELECTROSTATIC FORCE



$\vec{F}_{12} = -\vec{F}_{21}$ ARE NEWTON'S 3RD LAW PAIRS. THE MAGNITUDE OF THIS FORCE IS

$$F = \left(\frac{1}{4\pi\epsilon_0} \right) \frac{q_1 q_2}{r^2}$$

← CHARGES MAY BE POSITIVE OR NEGATIVE. LIKE CHARGES REPEL, OPPOSITES ATTRACT.

$$\frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2 \quad (\text{SOMETIMES CALLED } k)$$

COMPARE THE GRAVITATIONAL FORCE:

$$F = -G \frac{m_1 m_2}{r^2}$$

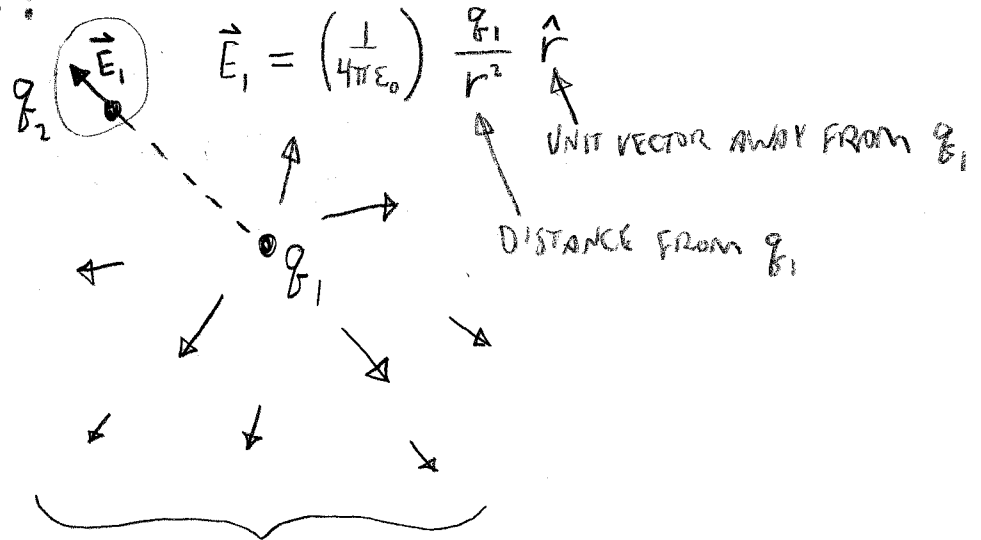
← MASS IS ALWAYS POSITIVE.

↑ FORCE IS ALWAYS ATTRACTIVE

DEMO: ELECTROSCOPE

ELECTRIC FIELDS

THE FORCE ON q_2 BY q_1 IS DUE TO THE ELECTRIC FIELD OF q_1 :



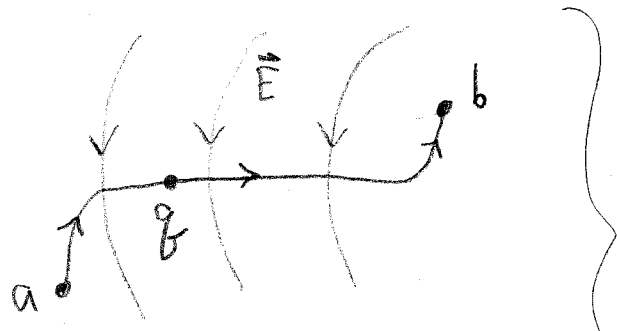
THE \vec{E} FIELD EXISTS EVERYWHERE, NOT JUST AT q_2 .

$$\vec{F}_{21} = q_2 \vec{E}_1 = \left(\frac{1}{4\pi\epsilon_0} \right) \frac{q_1 q_2}{r^2} \hat{r}$$

SO ELECTRIC FIELD CAN BE UNDERSTOOD AS A FORCE PER CHARGE.

ELECTRIC POTENTIAL (VOLTAGE, ELECTROMOTIVE FORCE)

IT TAKES WORK TO MOVE A CHARGE FROM ONE POINT TO ANOTHER IN AN ELECTRIC FIELD:



$$W_{ab} = \int_a^b \vec{F} \cdot d\vec{l} = \int_a^b q \vec{E} \cdot d\vec{l}$$

THE TEXT EXPLAINS ALL THIS WITHOUT RESORTING TO INTEGRALS. DON'T WORRY ABOUT THE MATH — IT IS THE CONCEPT THAT'S IMPORTANT.

SINCE THE CHARGE q IS A CONSTANT, WE CAN PULL IT OUT OF THE INTEGRAL:

$$W_{ab} = q \int_a^b \vec{E} \cdot d\vec{l}$$

WE DEFINE

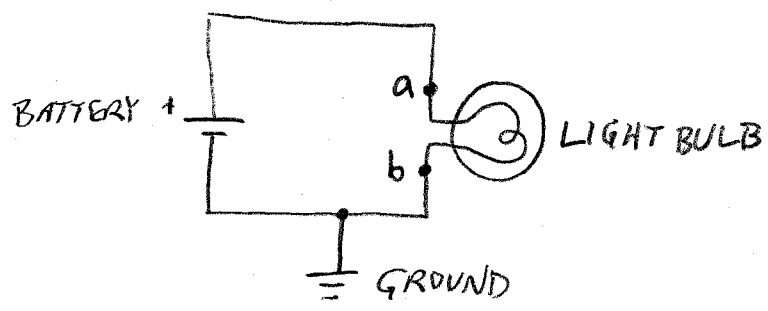
$$V_{ab} = \int_a^b \vec{E} \cdot d\vec{l} \quad \boxed{\text{UNITS: } \frac{J}{C}}$$

NOW, V_{ab} IS CALLED THE DIFFERENCE IN ELECTRICAL POTENTIAL OR THE VOLTAGE* BETWEEN POINTS a AND b .

- WE WILL NOT NEED INTEGRALS TO CALCULATE VOLTAGE IN CIRCUIT ANALYSIS. PUT THE VECTOR CALCULUS AWAY!
- THE RESULT DOES NOT DEPEND ON THE PATH TAKEN FROM a TO b . LIKE POTENTIAL ENERGY IN MECHANICS!

* ALSO CALLED ELECTROMOTIVE FORCE (EMF).

VOLTAGE IS A DIFFERENCE BETWEEN TWO POINTS. WE WILL COMMONLY MARK ONE POINT IN A CIRCUIT AS "GROUND" (OTHER COMMONLY USED WORDS FOR VOLTAGE REFERENCE POINTS INCLUDE "EARTH," "NEUTRAL," OR "COMMON"). WE CAN THEN TALK ABOUT THE VOLTAGE AT ANY ONE POINT IN THE CIRCUIT BY COMPARING TO GROUND.



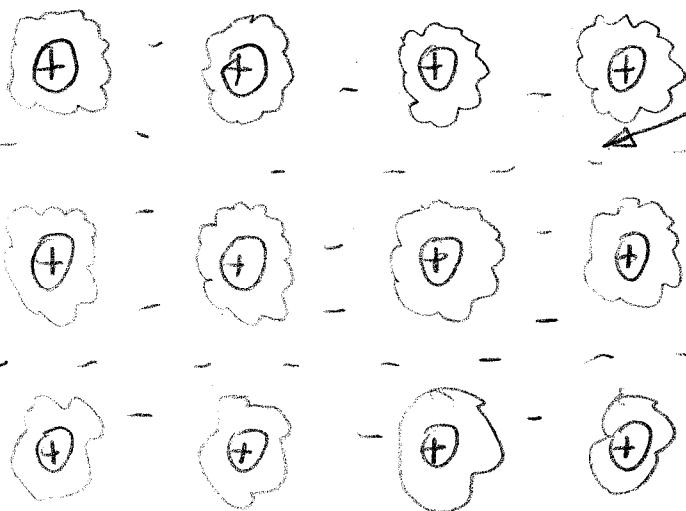
Q: IF THE BATTERY IS A "AA" SIZE CELL, WHAT IS V_a ? V_b ?

IT IS CONVENTIONAL TO PUT GROUND AT THE NEGATIVE TERMINAL OF THE POWER SOURCE, BUT THIS CONVENTION IS NOT ALWAYS FOLLOWED.

Q: IF WE PUT THE CIRCUIT GROUND AT THE BATTERY'S POSITIVE TERMINAL, WHAT IS V_a ? V_b ?

SOLID MATERIALS (AND CONDUCTORS)

EACH ATOM HAS INNER SHELL ELECTRONS THAT PARTLY SCREEN THE NUCLEUS. TAKEN TOGETHER, IT IS A LATTICE OF POSITIVE IONS



OUTER (VALENCE) ELECTRONS ARE SHARED WITH NEIGHBORING ATOMS TO VARYING DEGREES.

SOME SOLIDS HAVE AN ELECTRONIC STRUCTURE THAT ALLOWS ELECTRONS TO MIGRATE EASILY THROUGH THE LATTICE. THIS IS CALLED AN ELECTRIC CONDUCTOR.

ALL METALS ARE GOOD CONDUCTORS.

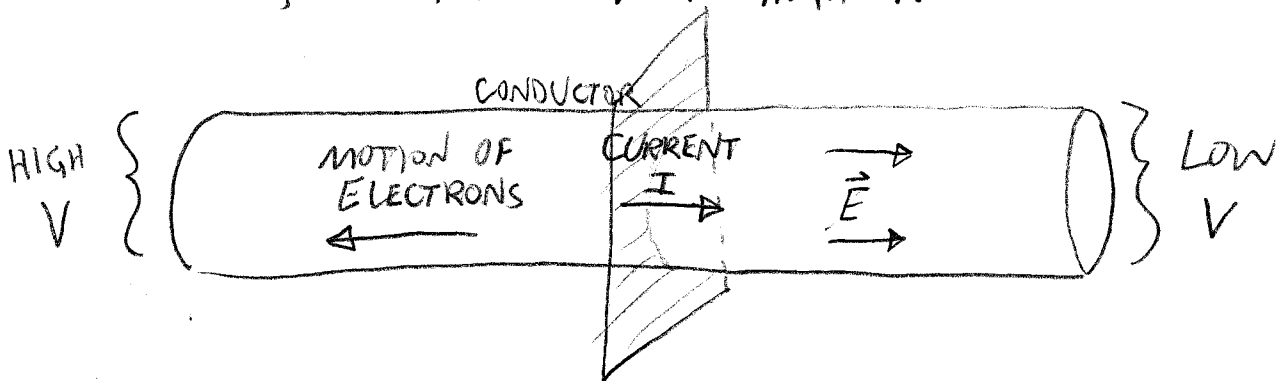
MATERIALS WITHOUT CONDUCTION ELECTRONS ARE CALLED INSULATORS.

SAMPLE

CURRENT

WHEN AN ELECTRIC FIELD IS APPLIED TO A CONDUCTOR,

- THE IONS EXPERIENCE A FORCE BUT ARE STUCK IN THE LATTICE — UNABLE TO MOVE.
- CONDUCTION ELECTRONS ARE FREE TO MOVE, SO THEY MOVE OPPOSITE THE DIRECTION OF \vec{E} , THAT IS, FROM LOW V TO HIGH V.



THE RESULTING CURRENT, I , IS DEFINED AS THE AMOUNT OF CHARGE PER SECOND PASSING THROUGH AN IMAGINARY SURFACE CUTTING THROUGH THE CONDUCTOR.

$$I = \frac{dQ}{dt}$$

UNITS:
AMPERES (A) \equiv C/s.

THE DIRECTION OF CURRENT IS DEFINED AS IF
THE CHARGE CARRIERS WERE POSITIVE.

RESISTANCE

GIVEN WHAT HAS BEEN SAID SO FAR, YOU MIGHT EXPECT A VOLTAGE APPLIED ACROSS A CONDUCTOR TO CAUSE THE CONDUCTION ELECTRONS TO ACCELERATE. THE CURRENT WOULD INCREASE UNTIL THE VOLTAGE IS REMOVED. THIS DOES NOT (NORMALLY) HAPPEN!

EVEN IN A GOOD CONDUCTOR, CURRENT GIVES RISE TO A "BACK EMF" — A VOLTAGE THAT OPPOSES THE FLOW OF CURRENT. THE MAGNITUDE OF THIS OPPOSING VOLTAGE IS GIVEN BY OHM'S LAW:

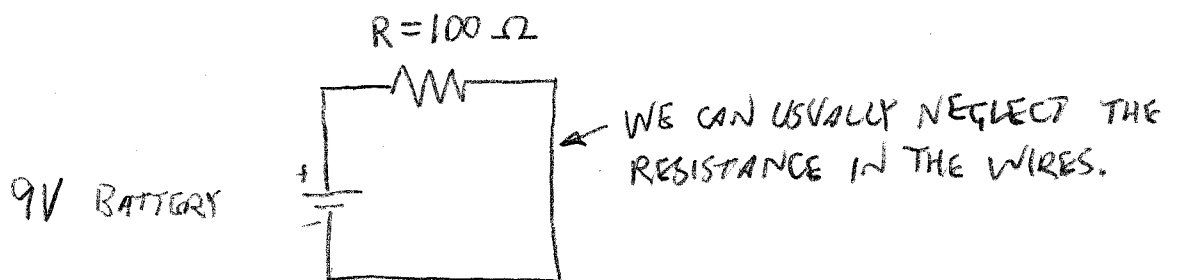
$$V = IR,$$

WHERE R IS THE RESISTANCE.

UNITS OF RESISTANCE:

$$\frac{V}{A} \equiv \Omega \text{ (OHM)}$$

AN EQUILIBRIUM IS QUICKLY REACHED IN WHICH THE APPLIED VOLTAGE EQUALS THE OPPOSING VOLTAGE GENERATED BY RESISTANCE.



$$I = V/R = \frac{9V}{100 \Omega} = .09 A = 90 \text{ mA}$$

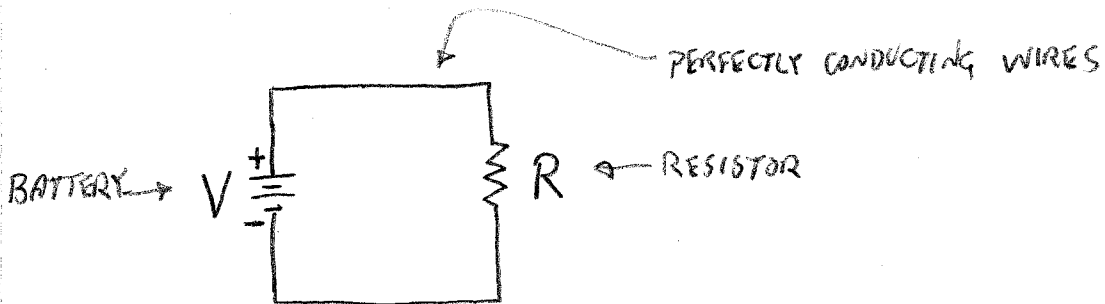
CAVEAT

"OHM'S LAW" REALLY MEANS NOT JUST THE DEFINITION OF RESISTANCE, $R \equiv V/I$, BUT THE EMPIRICALLY OBSERVED FACT THAT CURRENT TENDS TO BE PROPORTIONAL TO VOLTAGE IN MANY CONDUCTORS. THIS IS ONLY APPROXIMATE, AS YOUR TEXT POINTS OUT. HOWEVER, TO THE EXTENT THAT OHM'S LAW HOLDS, THE RESISTANCE OF A COMPONENT IS CONSTANT.

COMPAD

DISCUSSION

CONSIDER THE FOLLOWING SIMPLE CIRCUIT AS AN EXAMPLE:



Q: WHERE MIGHT EACH OF THE FOLLOWING QUANTITIES PERTAIN IN THE CIRCUIT?

- | | |
|--------------|------------------------------|
| ① VOLTAGE | Ⓐ AT A POINT |
| ② CURRENT | Ⓑ BETWEEN TWO POINTS |
| ③ RESISTANCE | Ⓒ FOR THE CIRCUIT AS A WHOLE |

POWER

Q: WHAT ARE THE UNITS OF THE QUANTITY $I \cdot V$?

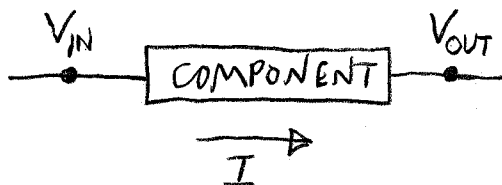
A: $I = C/s$ (CHARGE PER TIME)

$V = J/C$ (ENERGY PER CHARGE)

SO $IV = J/s = W$ (POWER)

WHAT THIS MEANS IN PRACTICE:

- LET $V =$ VOLTAGE ACROSS A (2-TERMINAL) COMPONENT.
- LET $I =$ CURRENT IN THAT COMPONENT.
- $P = IV$ IS THE POWER.



- IF THERE IS A VOLTAGE DROP ($V_{IN} > V_{OUT}$ FOR $I > 0$), THEN POWER $P = IV$ IS DISSIPATED IN THE COMPONENT.
- IF THERE IS A VOLTAGE RISE ($V_{OUT} > V_{IN}$ FOR $I > 0$), THEN THE COMPONENT IS PROVIDING POWER $P = IV$.

CONRAD