FIZ102E – Lecture 6
Direct-Current Circuits

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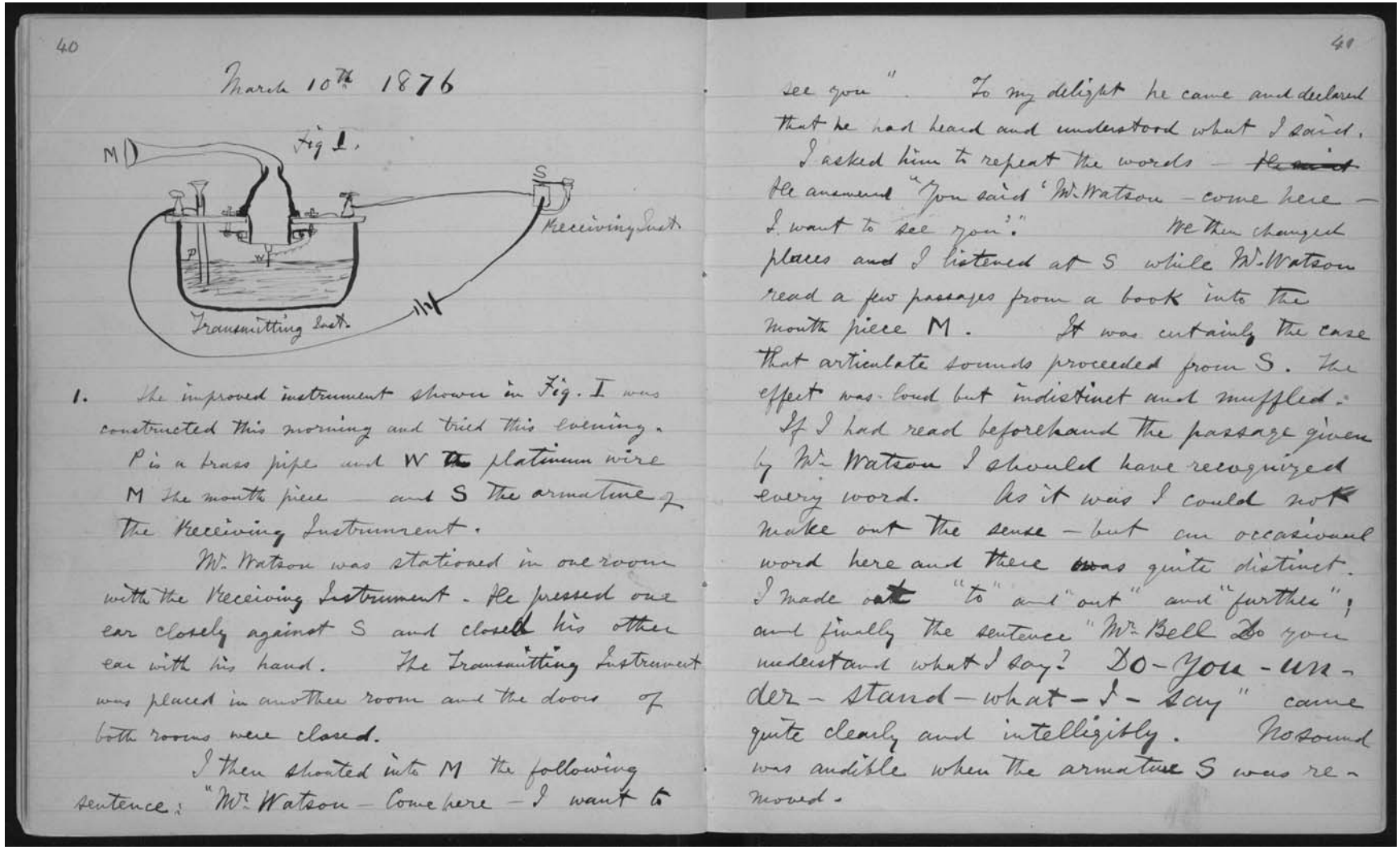
What did we cover last week?



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March 10th 1876

Fig. I.

1. The improved instrument shown in Fig. I was constructed this morning and tried this evening. P is a brass pipe and W the platinum wire M the mouth piece — and S the armature of the Receiving Instrument.

Mr. Watson was stationed in one room with the Receiving Instrument. He pressed one ear closely against S and closed his other ear with his hand. The Transmitting Instrument was placed in another room and the doors of both rooms were closed.

I then shouted into M the following sentence: "Mr. Watson — Come here — I want to see you". To my delight he came and declared that he had heard and understood what I said.

I asked him to repeat the words — ~~He said~~ He answered "You said 'Mr. Watson — come here — I want to see you'." We then changed places and I listened at S while Mr. Watson read a few passages from a book into the mouth piece M. It was certainly the case that articulate sounds proceeded from S. The effect was loud but indistinct and muffled.

If I had read beforehand the passage given by Mr. Watson I should have recognized every word. As it was I could not make out the sense — but an occasional word here and there was quite distinct. I made out "to" and "out" and "further"; and finally the sentence "Mr. Bell Do you understand what I say? DO-YOU-UN-DER-STAND-WHAT-I-SAY" came quite clearly and intelligibly. No sound was audible when the armature S was removed.

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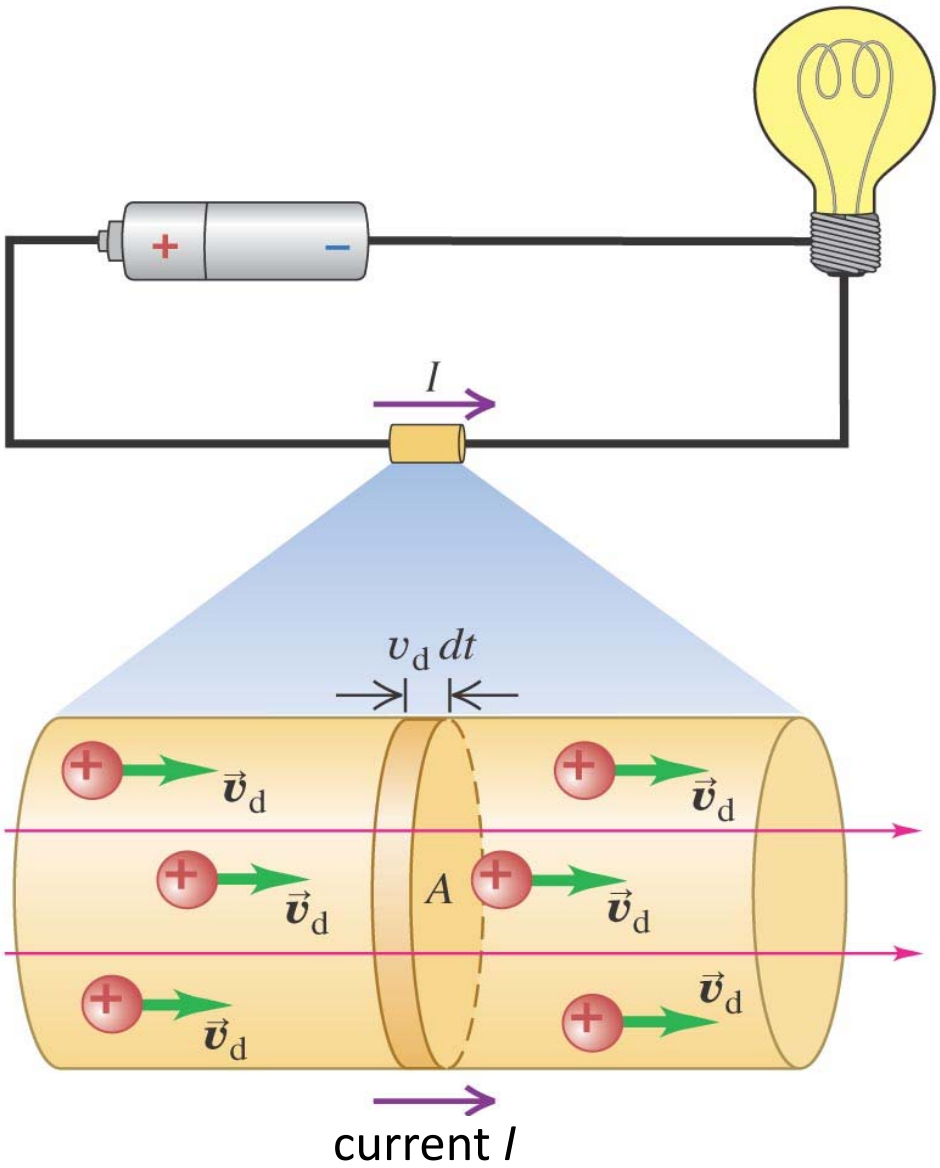
Electric current



Current: $$I = \frac{dQ}{dt} = n|q|v_d A$$

n . . . density of charge carriers

q . . . charge per carrier

v_d . . . drift velocity

A . . . conductor cross-section

Units:

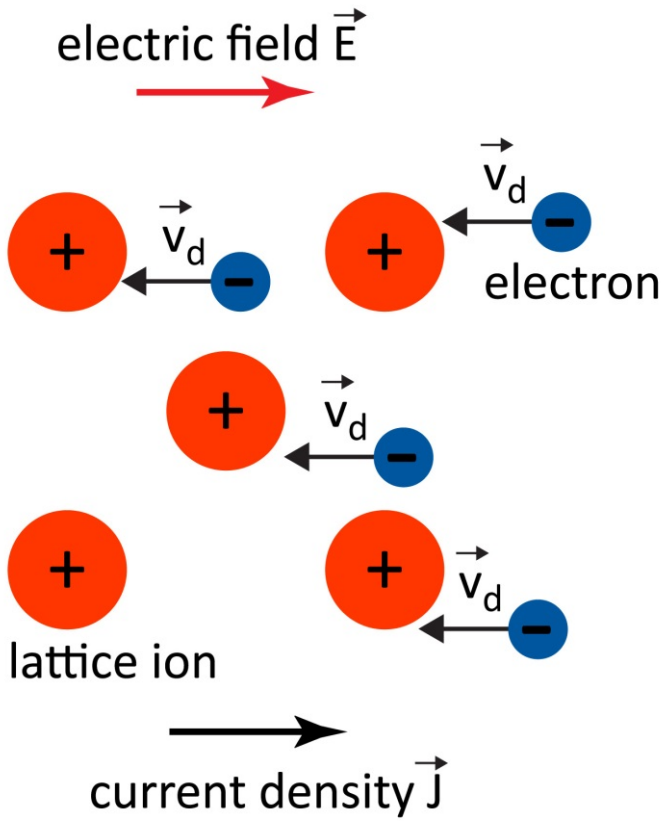
1 Ampere [A] = 1 C/s

Current density:

$$J = \frac{I}{A} = nqv_d \Rightarrow \vec{J} = nq\vec{v}_d$$

Current direction → along the flow of positive charge

Resistivity of conductors



Electrons moving in the electric field collide with vibrating lattice ions

→ electron motion is slowed down

→ material <u>resists</u> the motion

<u>Resistivity:</u>

$$\rho = \frac{|\vec{E}|}{|\vec{J}|} = \textbf{constant}$$

Units:

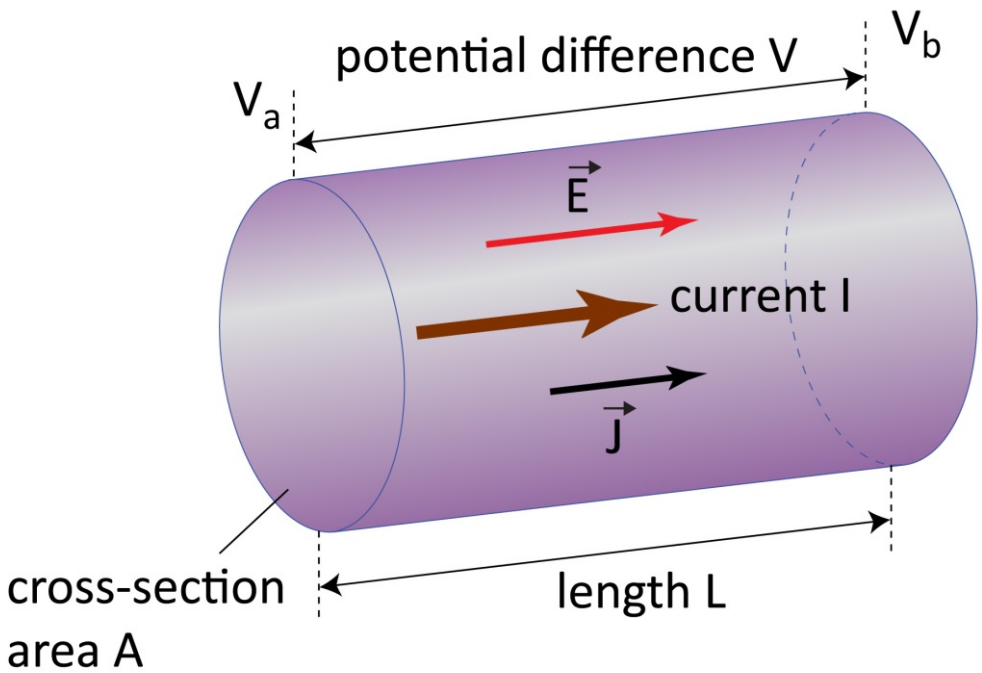
1 (V/A).m = 1 Ω.m

Resistivity of materials covers a huge range

<u>Example</u>: silver → conductor → $\rho = 1.47 \times 10^{-8}$ Ω.m

glass → insulator → $\rho = 10^{10} - 10^{14}$ Ω.m

Resistance



For a conductor, it holds:

$$\left|\vec{E}\right| = \rho \left|\vec{J}\right|$$

Uniform electric field: $\left|\vec{E}\right| = \dfrac{V}{L}$

Uniform current density: $\left|\vec{J}\right| = \dfrac{I}{A}$

"Ohm's law"

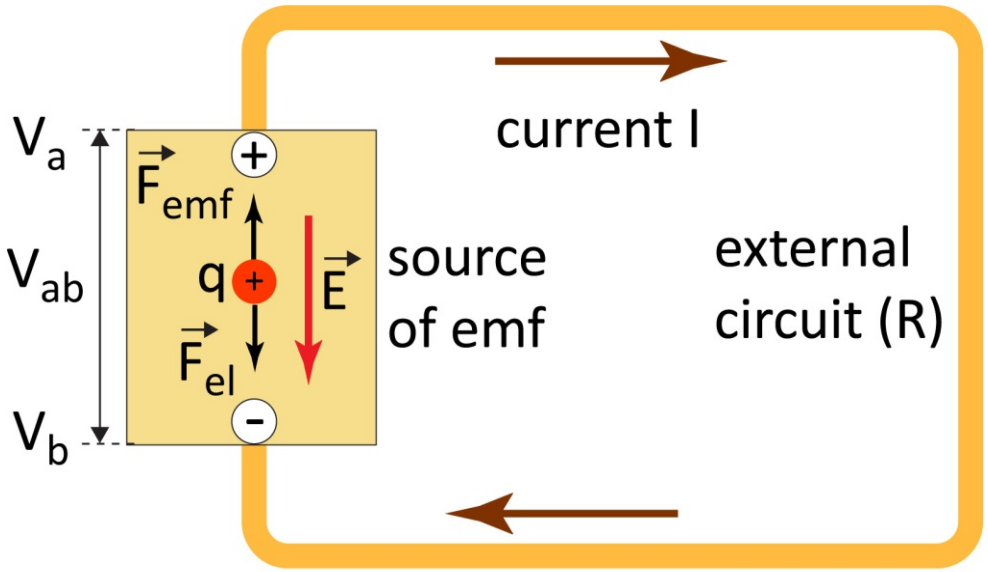
$$\frac{V}{L} = \frac{\rho I}{A} \quad \Rightarrow \quad V = \left(\frac{\rho L}{A}\right) I$$

$$\Rightarrow \quad V = R\,I$$

where $R = \left(\dfrac{\rho L}{A}\right)$ defines <u>resistance</u>

Units: 1 Ohm = 1 Ω

Electromotive force and circuits



In order to keep the current flowing, we need a device that "lifts" charge q from lower potential V_b to higher potential V_a against the electric force F_{el}

$$\Downarrow$$

Source of electromotive force (emf) $\mathcal{E}$ that uses non-electrostatic energy (chemical, thermal, mechanical, solar…) for charge transport

Electromotive force and circuits

Units of emf: 1 V → identical to potential difference

External circuit with resistance <u>*R*</u>:

$$\boxed{V_{ab} = R\,I}$$

Transport of charge through the source of emf with internal resistance <u>*r*</u>:

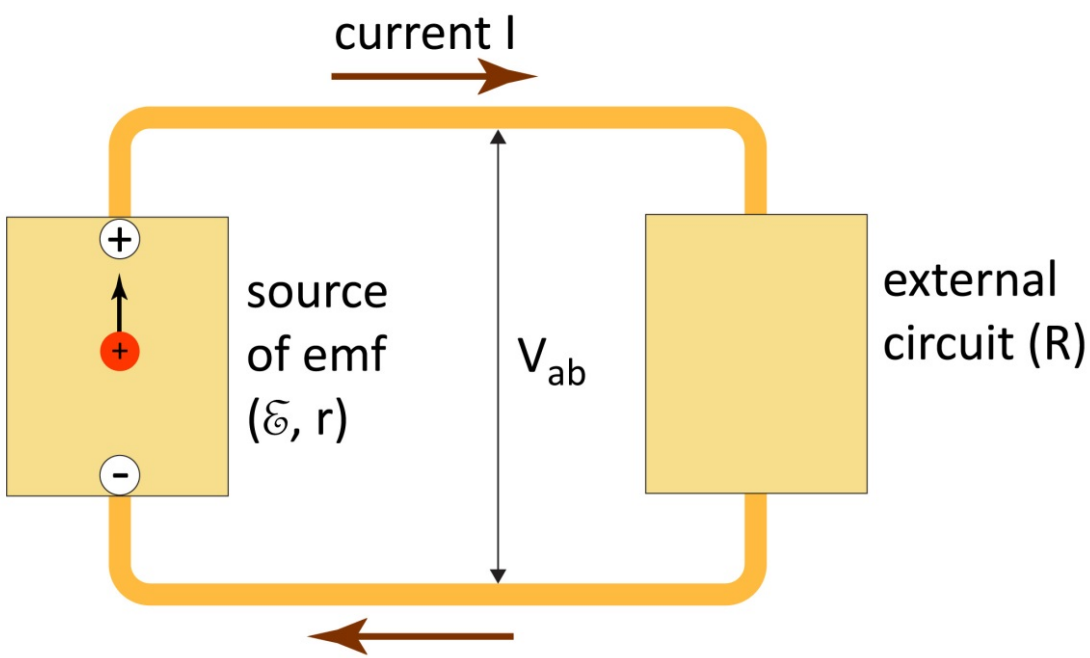
$$\boxed{V_{ab} = \mathcal{E} - r\,I}$$

Circuit balance:

$$\boxed{\mathcal{E} = (R + r)I} \Rightarrow \boxed{I = \frac{\mathcal{E}}{(R + r)}}$$

Current in the circuit depends on the total circuit resistance (including internal resistance)

Energy and power in electric circuits



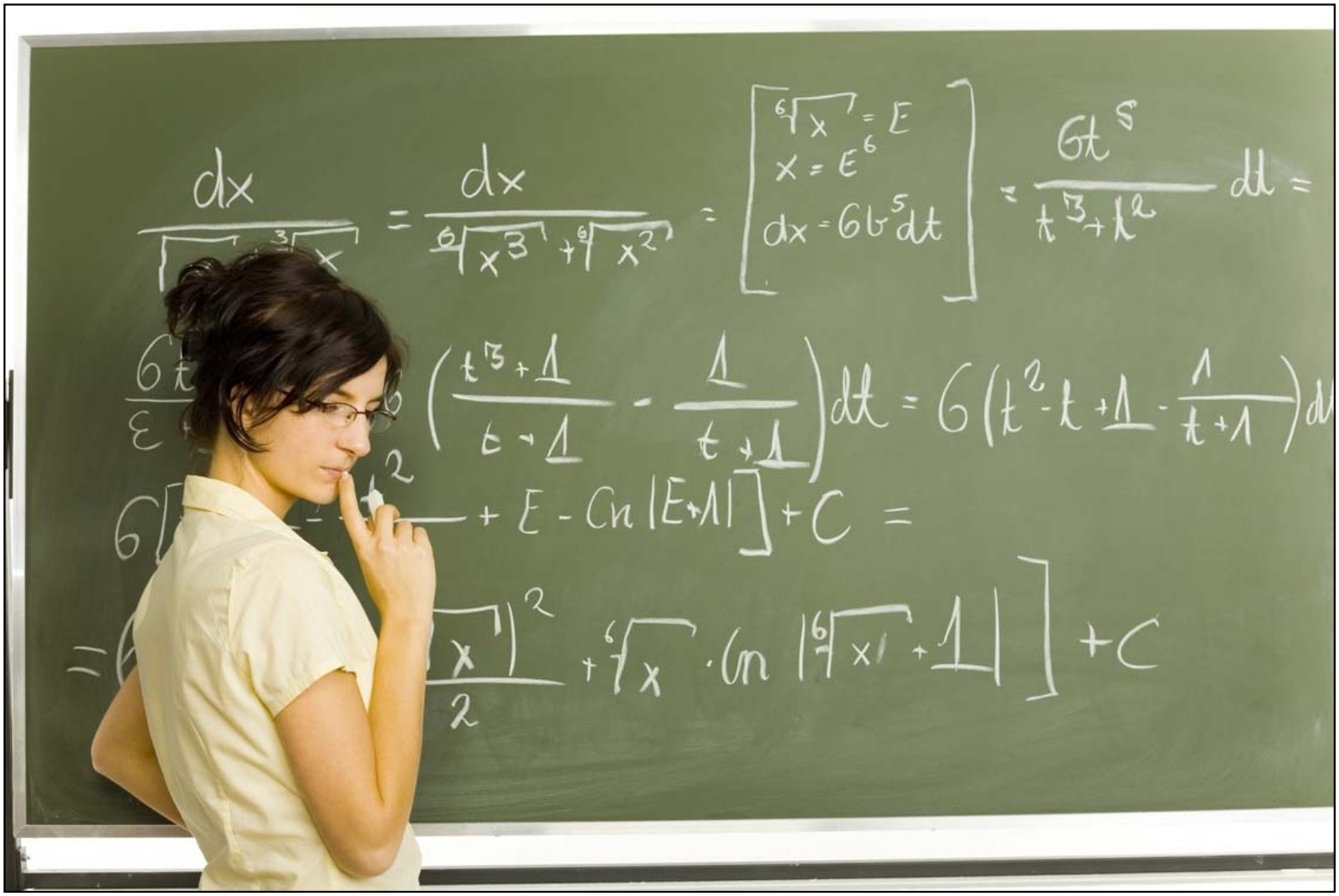
Power delivered to external resistance <u>*R*</u>: $$\boxed{P = V_{ab}\, I = I^2 R = \frac{V_{ab}^2}{R}}$$

Circuit balance: $$\boxed{P = V_{ab}\, I = (\mathcal{E} - r\, I) I = \mathcal{E} I - I^2 r}$$

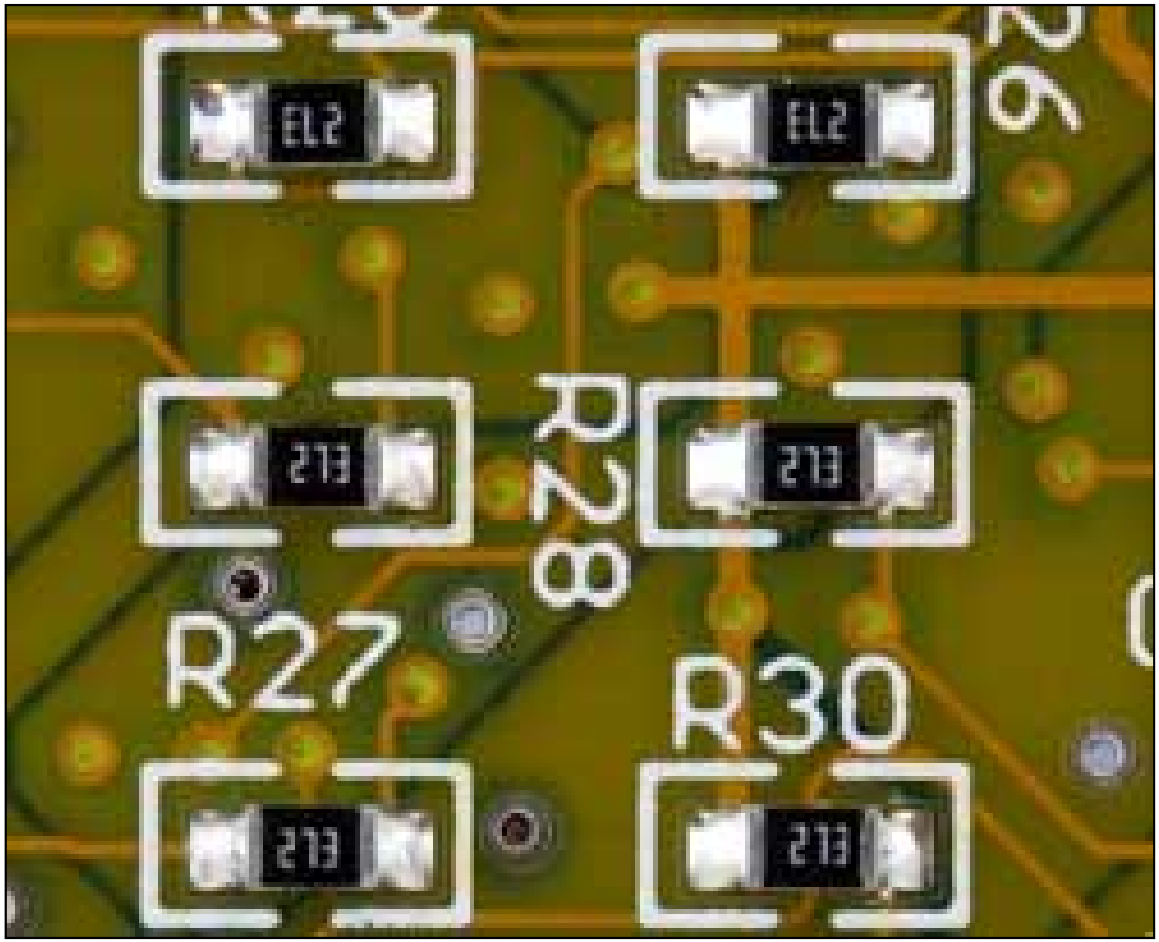
where: $\mathcal{E} I$ . . . useful work done by the source of emf

$I^2 r$ . . . power dissipated inside the source of emf (heat)

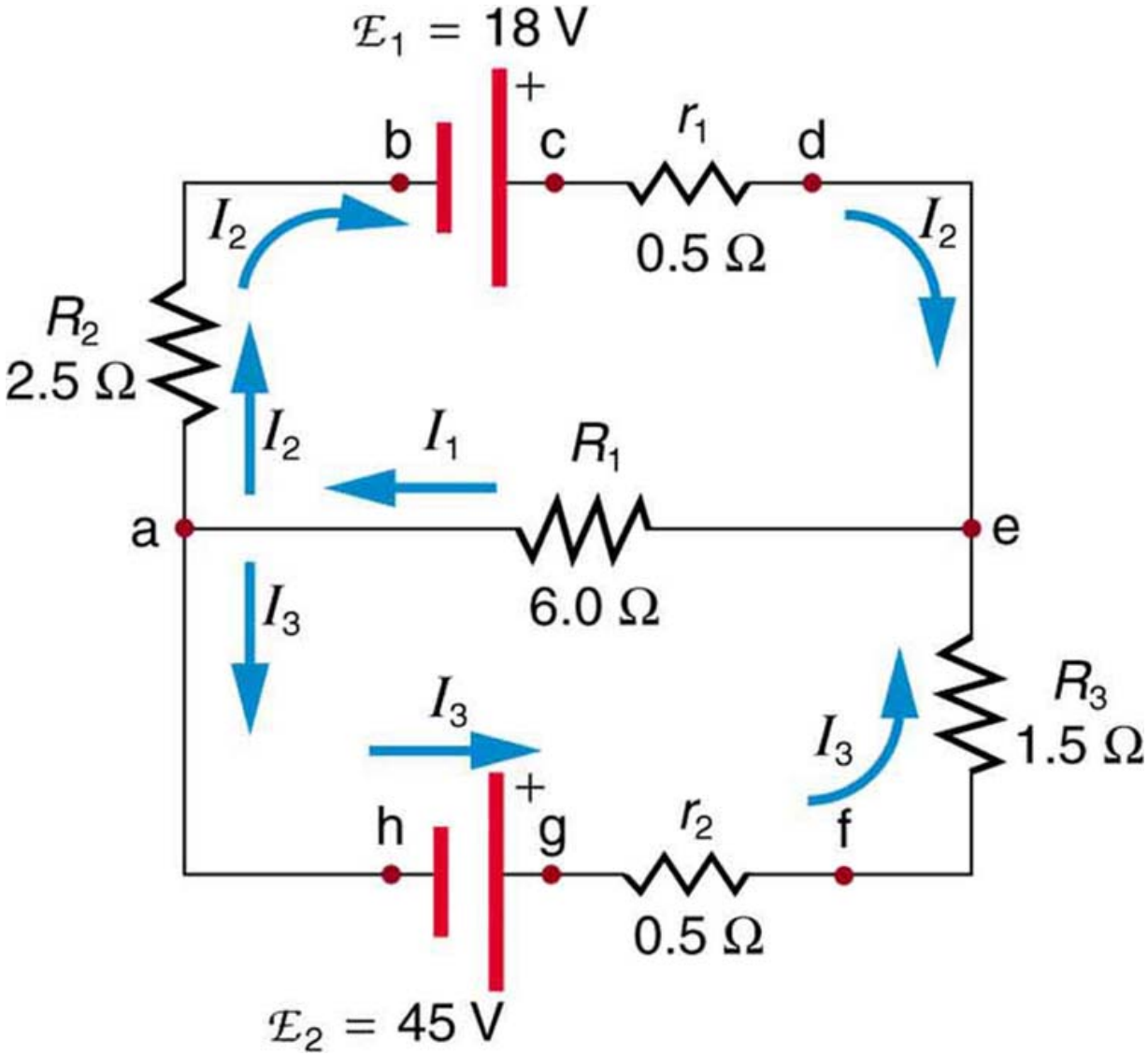
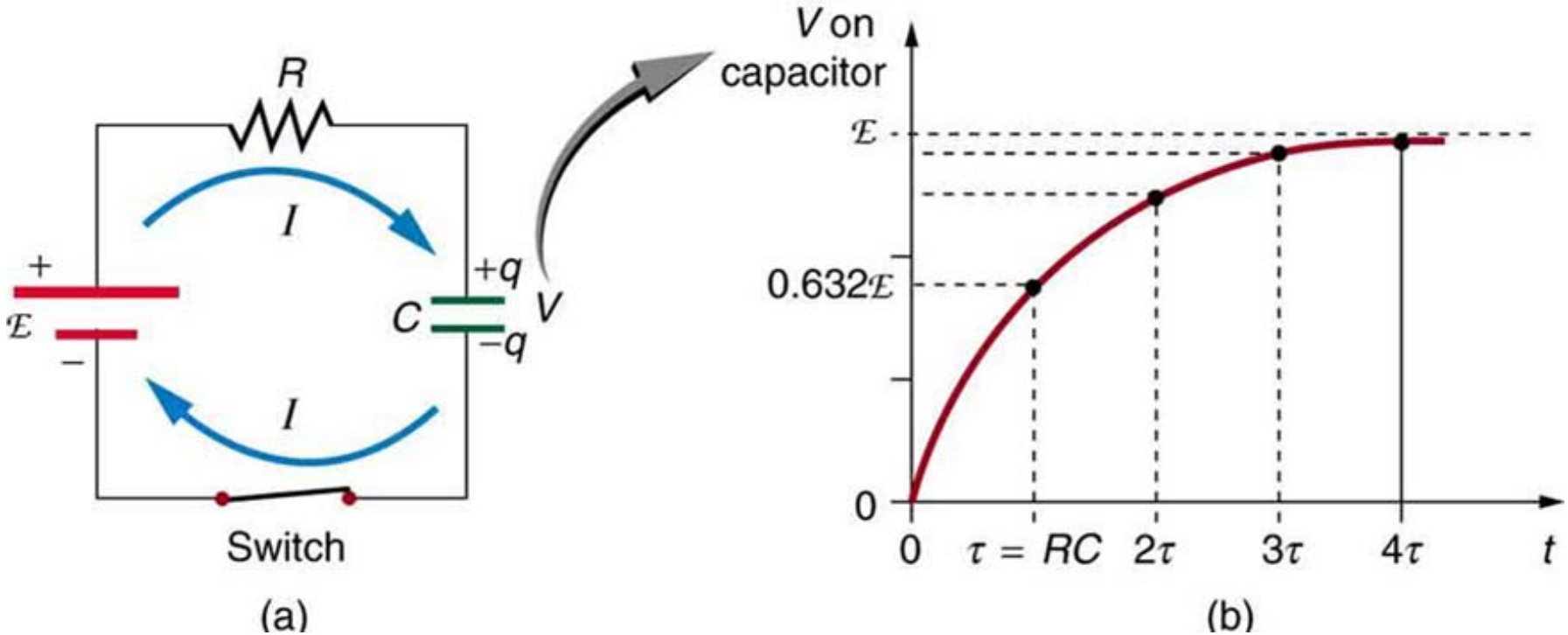
What will we cover today?



Resistors in series and parallel



Kirchhoff's rules



R-C circuits