Chapter 3 Steady Electric Current

3.1 Steady-State Condition

3.2 Resistance and the Ohm's Law

3.3 Electromotive Force and Kirchhoff's law

3.3 EMF and Kirchhoff's Laws

Electromotive Force- EMF

- What makes charges flow in circuits?

  Potential difference ΔV

  Source of charges

- This is what the EMF provides

  Note: EMF=Electromotive force but it's not a force!!!

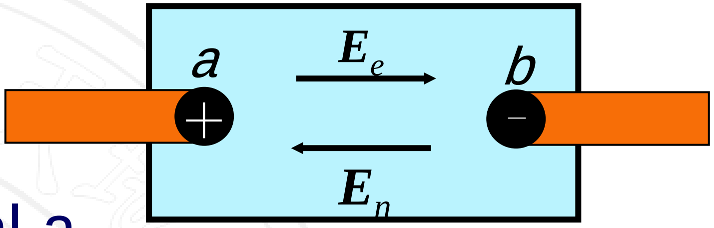
- Example of EMF: battery

  Device that maintains separation of charges between 2 electrodes

  Current flows inside via electrochemical reactions that produce ε

3.3 EMF and Kirchhoff's Laws

◈ Electromotive Force- EMF



electrostatic field E_e
non-static field E_n

- Terminal b provides free electrons
- Positive charges appear on terminal a

  Both due to EMF (reaction)

  Electric field E_e appears between a&b

- When $E_e = E_n$, the charges on each terminal don't change.
- EMF is defined as the work done by E_n to move a unit positive charge from – to +

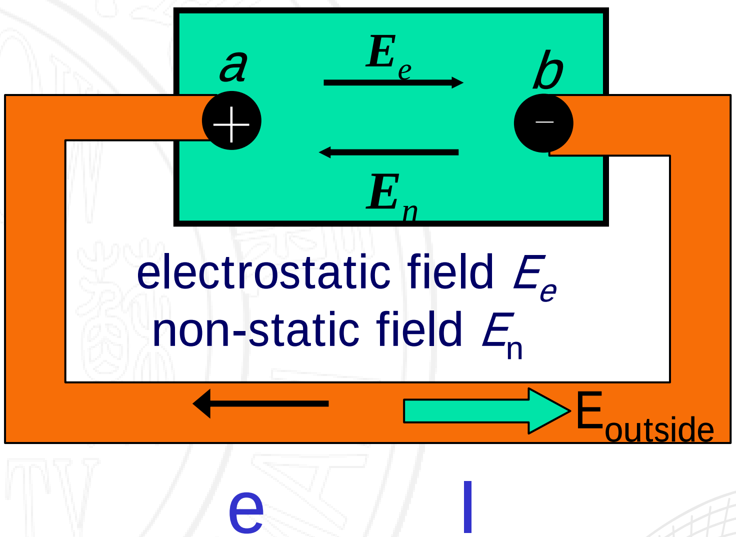
$$\varepsilon = \int_{-}^{+} \vec{E}_n \cdot d\vec{l}$$

3.3 EMF and Kirchhoff's Laws

◈ Electromotive Force- EMF

outside circuit closed, electrons move to +, E_e decreased

The reaction occurs again to maintains the potential difference between a & b.



$$V_{ab} = \int_a^b \vec{E}_{outside} \cdot d\vec{l} = IR$$

Potential difference

External resistance

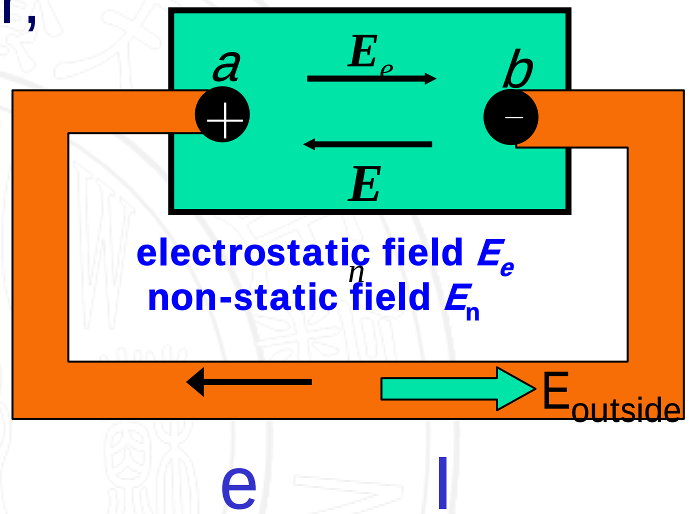
If there is no internal resistance, $\varepsilon = V_{ab}$

3.3 EMF and Kirchhoff's Laws

The terminal Voltage and EMF

If there is an internal resistance r, it will dissipate energy from the source.

When discharging, the energy provided in unit time by the source will be dissipated partly by the internal resistance, the others will output to outside circuit.



Show source work

Run flash. exe first

$$\varepsilon dq = Irdq + Vdq$$

$$\varepsilon = Ir + V \quad \text{or} \quad V = \varepsilon - Ir$$

3.3 EMF and Kirchhoff's Laws

The Condition of Most Output

- Ohm's law for whole circuit

$$I = \frac{\varepsilon}{R + r}$$

When discharging, we can derive the condition that a source exports the most energy

$$p = I^2 R = \frac{\varepsilon^2 R}{(r + R)^2}$$

$$\frac{dp}{dR} = 0 \qquad R=r$$

3.3 EMF and Kirchhoff's Laws

The Condition of Most Output

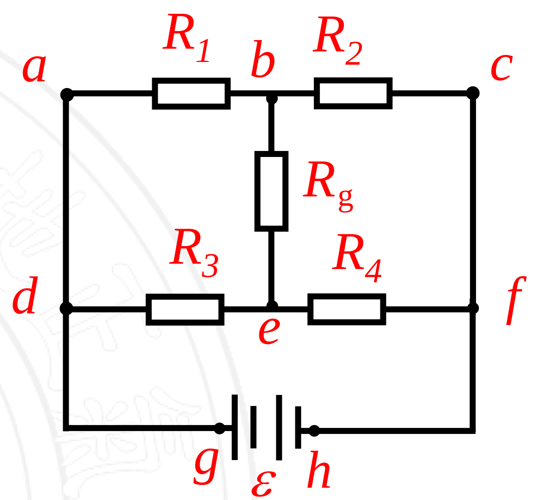
When charging, the energy provided in unit time by other source will be dissipated partly by the internal resistance, the others will transform to chemical energy of the source.

$$Vdq = Irdq + \varepsilon dq$$

$$V = Ir + \varepsilon$$

3.3 EMF and Kirchhoff’ s Laws

◈ Kirchhoff ’s first Law



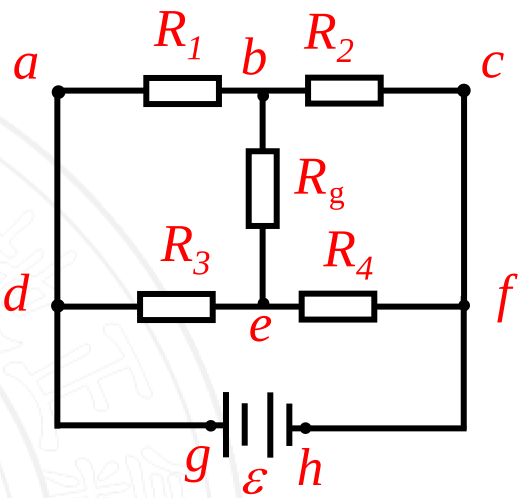
- Branch：a circuit made up of EMFs, resistors in series, such as dab,bcf,
- Node: the point that some branches combine, such as b,e,d,f
- Kirchhoff ’s first Law

Point rule (current law for node or junction theorem) The algebraic sum of the currents toward any node is zero

3.3 EMF and Kirchhoff's Laws

- Kirchhoff 's first Law

  At any given node, the sum of incoming currents is equal to the sum of the outgoing currents



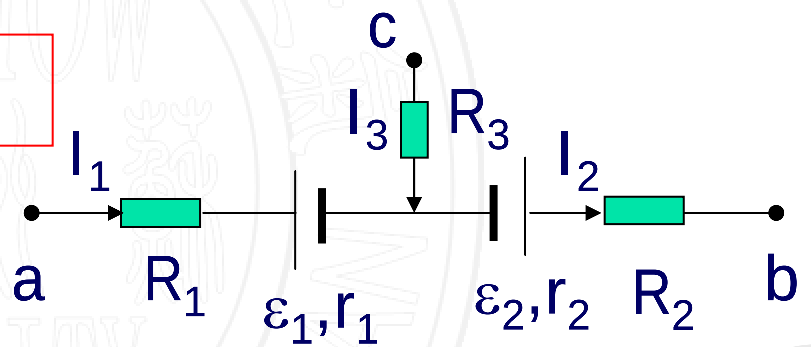
$$\sum(\pm I) = 0$$

3.3 EMF and Kirchhoff's Laws

Kirchhoff 's Second Law

Loop rule(voltage law) The algebraic sum of the voltage drop in any loop, including those associated with emfs and those of resistive elements, must equal zero:

$$\sum(\pm\varepsilon)+\sum(\pm IR)=0.$$



What is voltage drop?

$$V_{ab}=I_1(R_1+r_1)+I_2(R_2+r_2)+\varepsilon_1-\varepsilon_2$$

$$V_{ac}=I_1(R_1+r_1)-I_3R_3+\varepsilon_1$$

$$I_2=I_1+I_3$$

3.3 EMF and Kirchhoff' s Laws

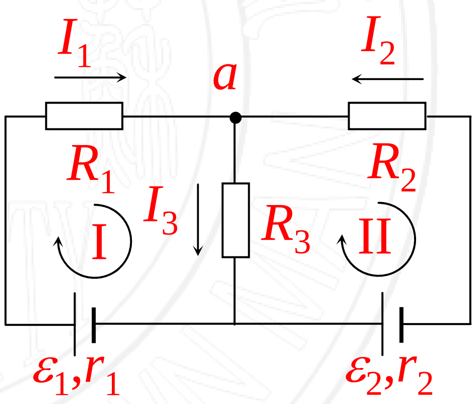
Example 3.3 In the circuit shown in the figure, find the unknown current I_1, I_2, I_3, Known quantities are R_1=4Ω, R_2=2Ω, R_3=2Ω, ε_1=18*V* and ε_2=14*V* .

Solution: Application of the node law to point *a* yields the relation

$$Node\ a: I_1+I_2=I_3$$

I: $-e_1+I_1R_1+I_3R_3=0$

II: $-\varepsilon_2-I_2R_2-I_3R_3=0$



$$-18+4I_1+2I_3=0$$

$$-14-2I_2-2I_3=0$$

I_1=5(A), I_2=-6(A), I_3=-1(A).