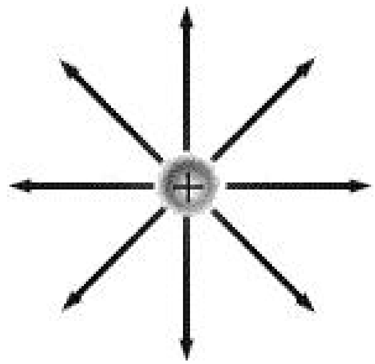
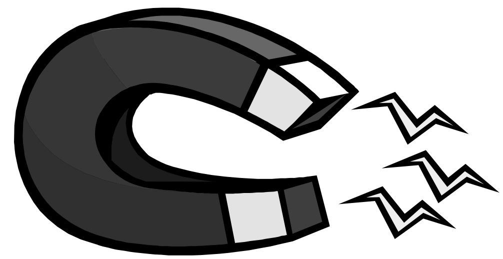
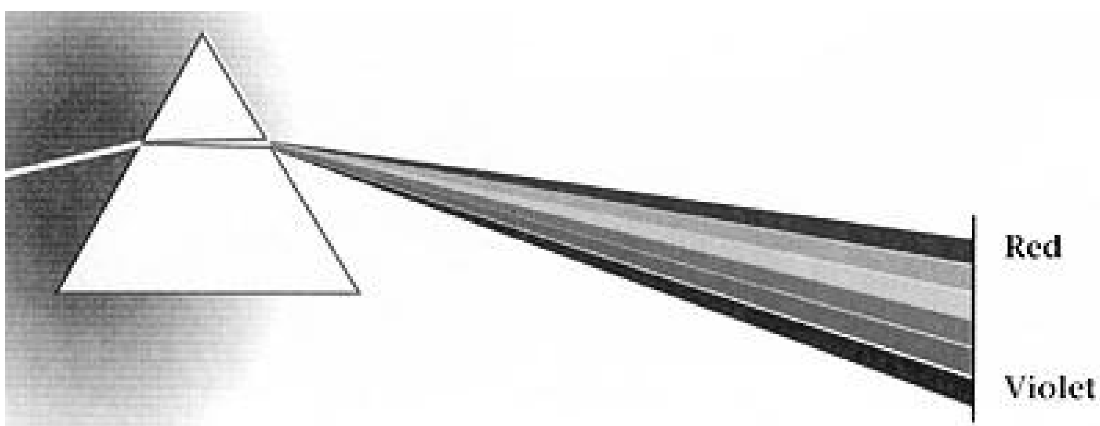
Elektrostatica 

Magnetostatica 

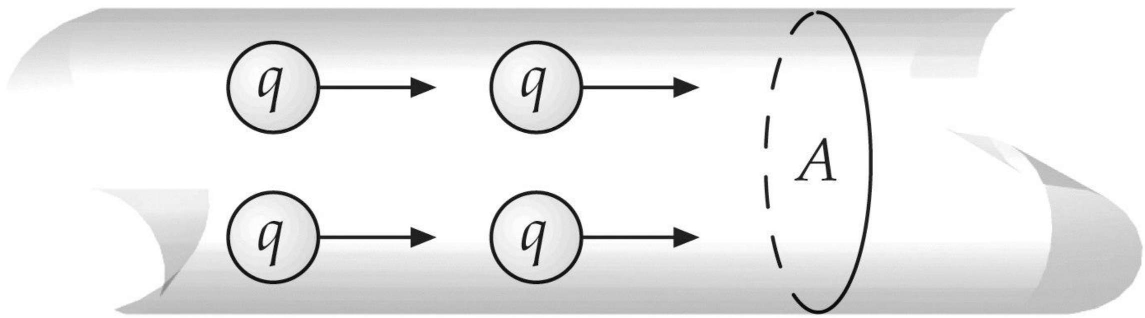
→ Elektromagnetisme ⇒ Licht



Wet van Ohm

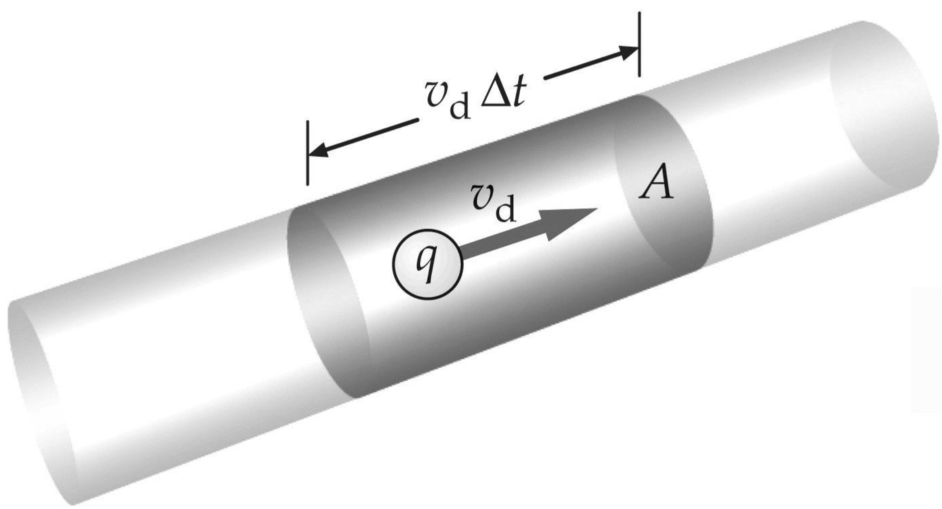
Wet van Ohm
Voorbeelden

Wet van Ohm



$$I = \frac{\Delta Q}{\Delta t} \qquad \text{25-1}$$

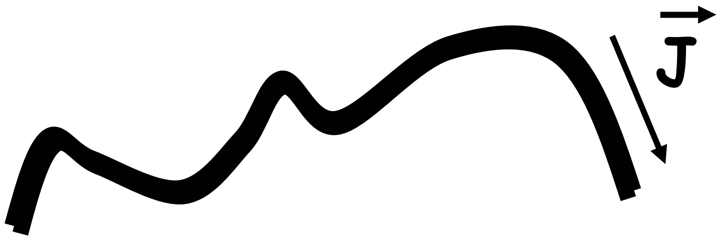
DEFINITION—ELECTRIC CURRENT



$$I = \frac{\Delta Q}{\Delta t} = qnAv_d \qquad \text{25-3}$$

RELATION BETWEEN CURRENT AND DRIFT VELOCITY

Waarom stroomt lading?



	Materiaal	$[\sigma]=(\Omega m)^{-1}$
geleider	koper	$6*10^{+7}$
	goud	$4*10^{+7}$
half-geleider	silicium	30
	germanium	2
isolator	rubber	10^{-14}
	glas	10^{-12}
	water	$4*10^{-6}$

$\vec{J} \propto \vec{f}$ met $\vec{f}$ kracht/lading

$\Rightarrow \vec{J} \equiv \sigma \vec{f}$ σ heet de "geleiding"

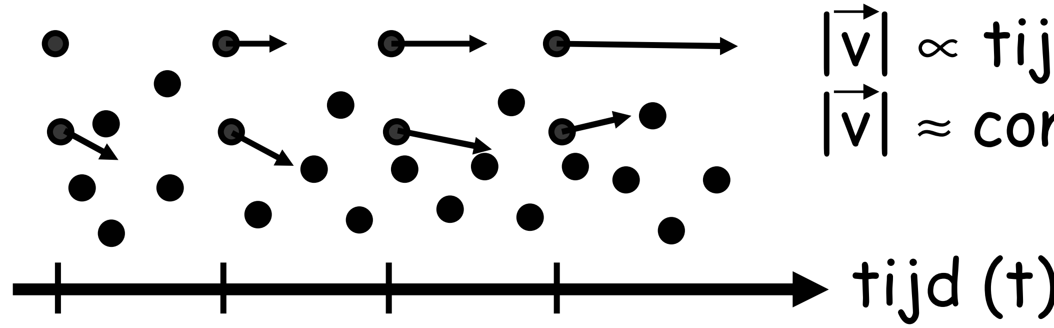
d.w.z. geleiders: $\sigma \to \infty$

isolatoren: $\sigma \to 0$

kracht/lading $\vec{f}$

* batterij
* van de Graaff
* dynamo
* etc.

waarom $\vec{J}$ slechts $\propto \vec{f}$? (empirisch verband)

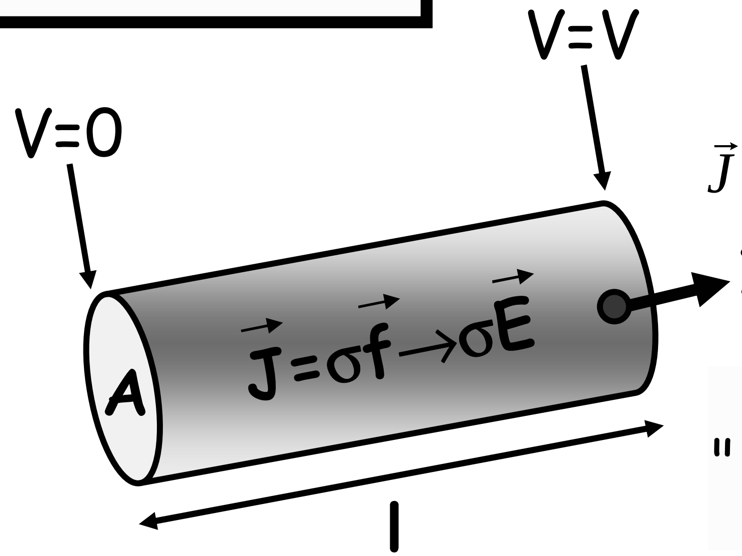


$|\vec{v}| \propto$ tijd

$|\vec{v}| \approx$ constant

V=IR
Wet van Ohm

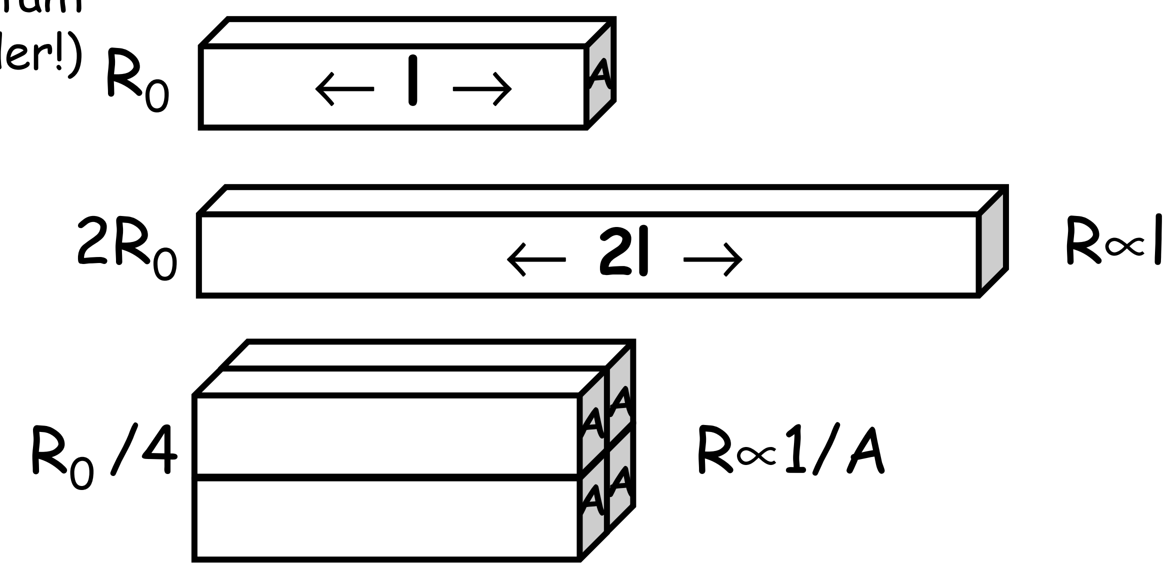
V.b. draadstuk



$$\vec{J} = \sigma \vec{E} \quad \begin{cases} |\vec{E}| = \dfrac{V}{l} \\ |\vec{J}| = \dfrac{I}{A} \end{cases} \Rightarrow \begin{cases} |\vec{J}| = \dfrac{I}{A} = \sigma |\vec{E}| = \sigma \dfrac{V}{l} \Leftrightarrow \\ V = I \dfrac{l}{\sigma A} \equiv IR \quad \text{s} \quad R \equiv \dfrac{l}{\sigma A} \end{cases}$$

"weerstand [R] = Ω" $R = \dfrac{l}{\sigma A}$; "[s]" :

Let op: σ=∞ ⇒ E=0, R=0, V=constant
(ideale geleider; nu echte geleider!)



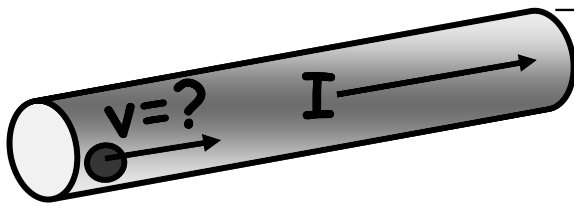
V.b. koperdraad:
1 meter lang
∅ 1 mm ⇒ Opp=0.75 mm^2
$\sigma = 6*10^{+7}\ (\Omega m)^{-1}$

⇒ $R = 1/(6*10^{+7}*0.75*10^{-6})$
$\approx 0.02\ \Omega$

Vragen

I. Hoe snel "driften" de elektronen in een stroomdraad?

$I=1A$, $e^-=1.6*10^{-19}$ C
$\varnothing$ 1 mm $\Rightarrow$ Opp$\approx 0.75mm^2$
$N_A=6*10^{+23}$/Mol
63.5g/Mol
$Z_{Cu}=29$; $2e^-$/Cu
$\rho_{Cu}\approx 9g/cm^3 \Rightarrow \#e^-/m^3 \approx 1.7*10^{+29}$

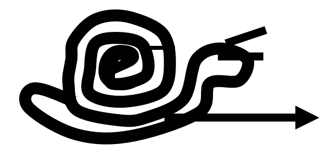


$$I = 1A = \frac{1C}{1s} \equiv |\vec{v}| * Opp * C/e^- * e^-/m^3$$

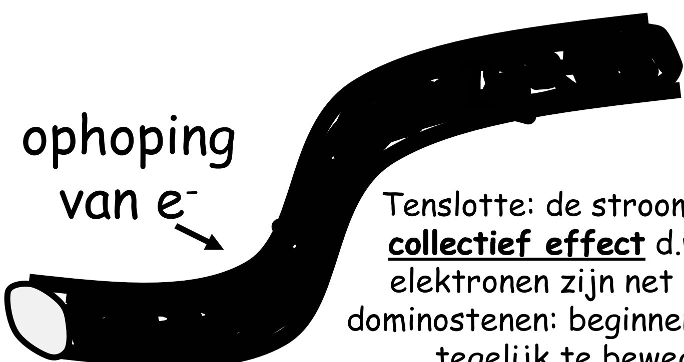
$$\Rightarrow |\vec{v}| = \frac{1C/s}{Opp*C/e^-*e^-/m^3} \qquad \left(|\vec{v}| = \frac{I}{Opp*e*n_e}\right)$$

$$\approx \frac{1}{0.75*10^{-6}*1.6*10^{-19}*1.7*10^{+29}}$$

$$\approx 5.1*10^{-5} m/s = 51 \mu m/s \approx 15 cm/uur$$



II. Waarom is de stroom "direct" aan?

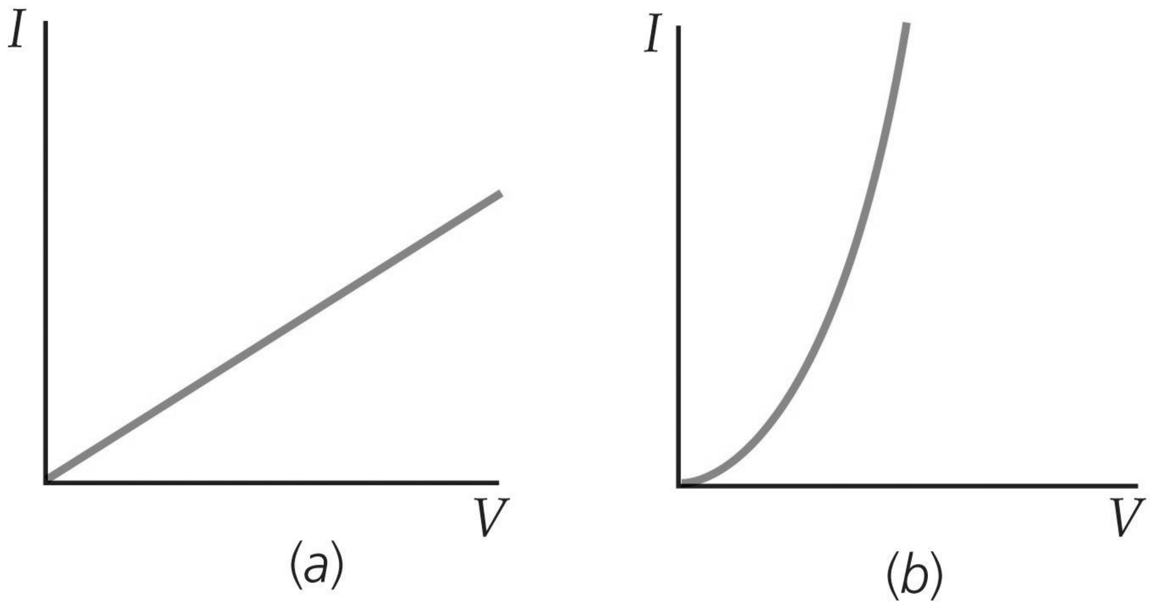


Tenslotte: de stroom is een **collectief effect** d.w.z. de elektronen zijn net een rij dominostenen: beginnen allemaal tegelijk te bewegen!

lokale ophoping
$\Rightarrow$ vertraagt inkomende e^-
$\Rightarrow$ versnelt uitgaande e^-

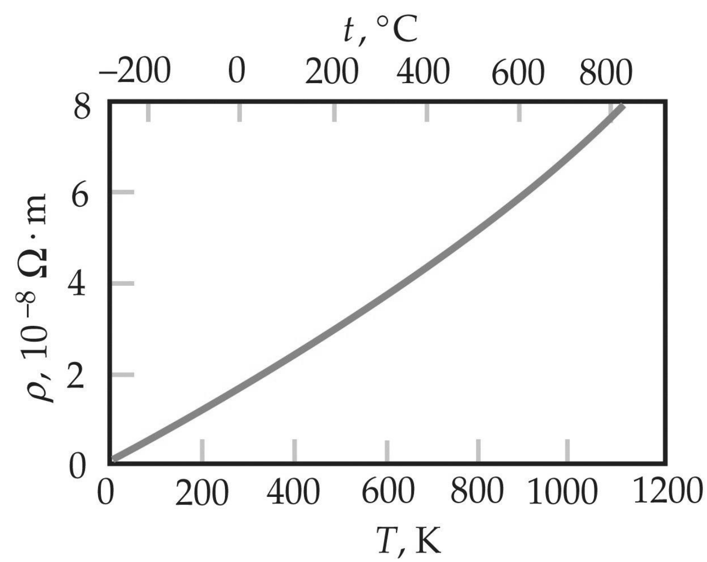
dus: automatisch "compensatie" mechanisme & instantaan!

Wet van Ohm



$V = IR, \quad R \text{ constant}$ 25-7

OHM'S LAW



Geleiding en soortelijke weerstand

$$\sigma = 1/\rho$$

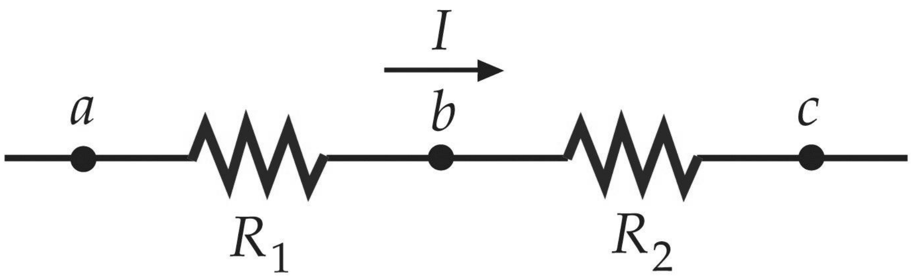
$$\text{"weerstand } [R] = \Omega\text{"} \quad R = \frac{l}{\sigma A};$$

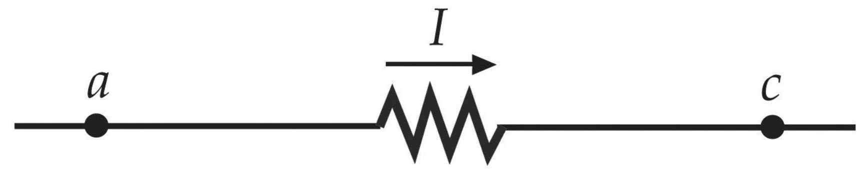
TABLE 25-1

Resistivities and Temperature Coefficients

Material	Resistivity ρ at 20°C, $\Omega\cdot$m	Temperature Coefficient α at 20°C, K^{-1}
Silver	1.6×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Aluminum	2.8×10^{-8}	3.9×10^{-3}
Tungsten	5.5×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Lead	22×10^{-8}	4.3×10^{-3}
Mercury	96×10^{-8}	0.9×10^{-3}
Nichrome	100×10^{-8}	0.4×10^{-3}
Carbon	3500×10^{-8}	-0.5×10^{-3}
Germanium	0.45	-4.8×10^{-2}
Silicon	640	-7.5×10^{-2}
Wood	$10^{8} - 10^{14}$	
Glass	$10^{10} - 10^{14}$	
Hard rubber	$10^{13} - 10^{16}$	
Amber	5×10^{14}	
Sulfur	1×10^{15}	

Circuits van weerstanden

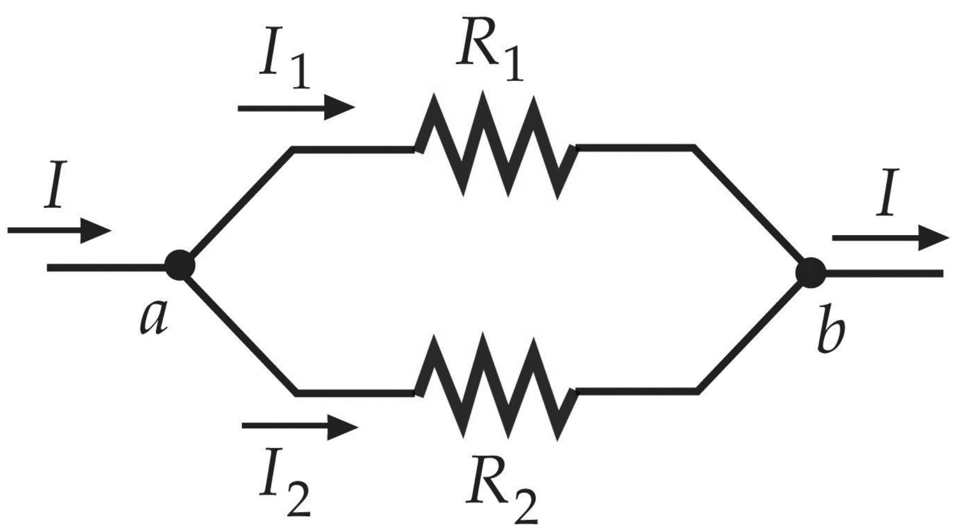


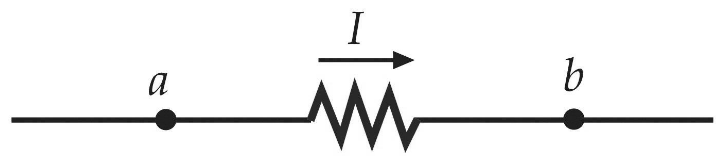


$$R_{eq} = R_1 + R_2$$

$$R_{eq} = R_1 + R_2 + R_3 + \ldots \qquad 25\text{-}17$$

EQUIVALENT RESISTANCE FOR RESISTORS IN SERIES





$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \qquad 25\text{-}21$$

EQUIVALENT RESISTANCE FOR RESISTORS IN PARALLEL

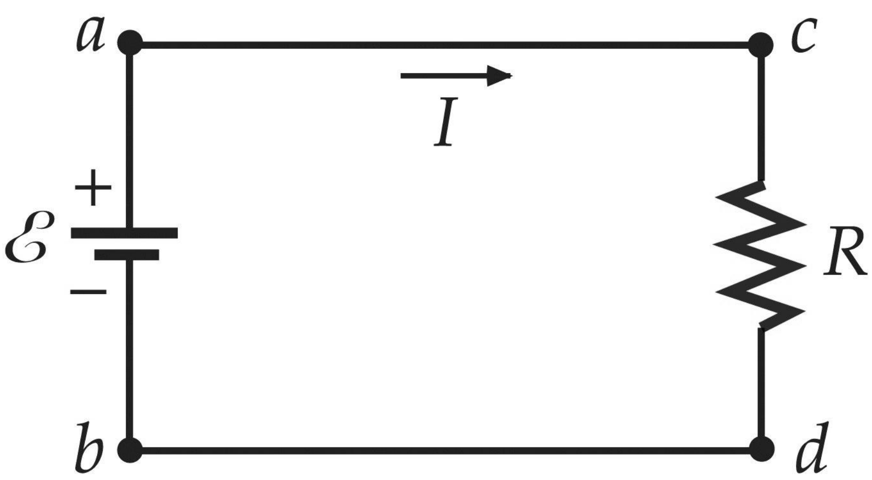
Elektromotorische kracht (EMK)

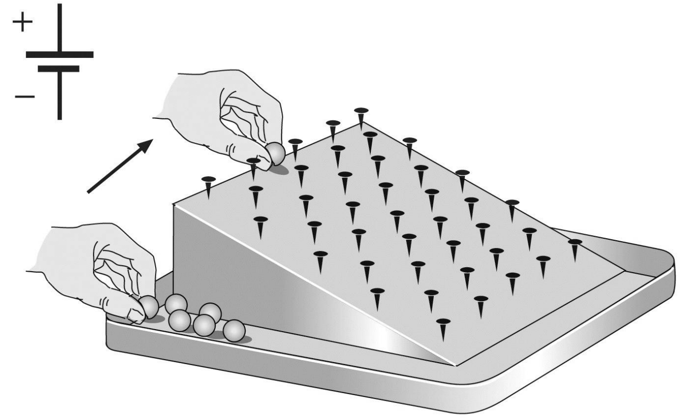
Definitie EMK

Inductie

Voorbeelden

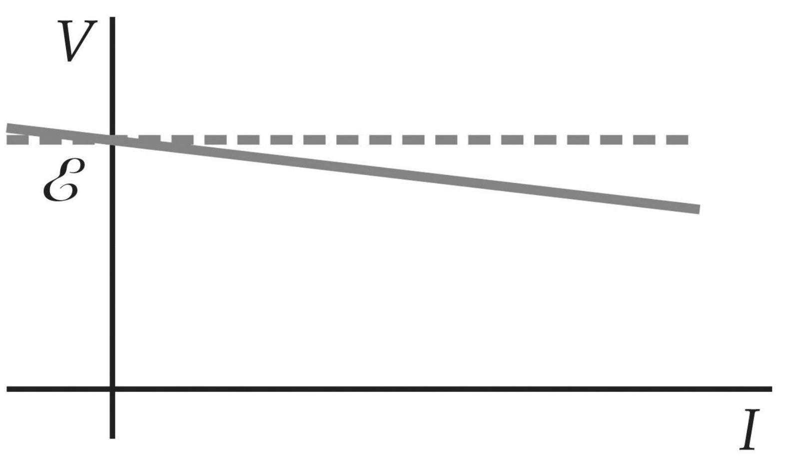
Elektromotorische kracht

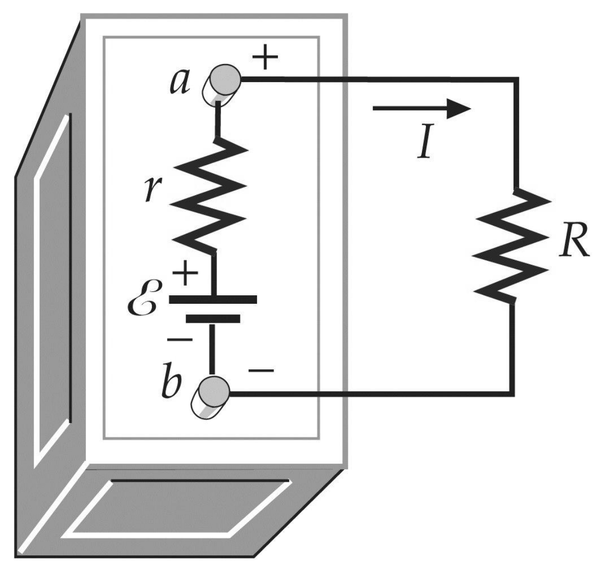




$$P = \frac{\Delta Q \mathcal{E}}{\Delta t} = I\mathcal{E} \qquad 25\text{-}12$$

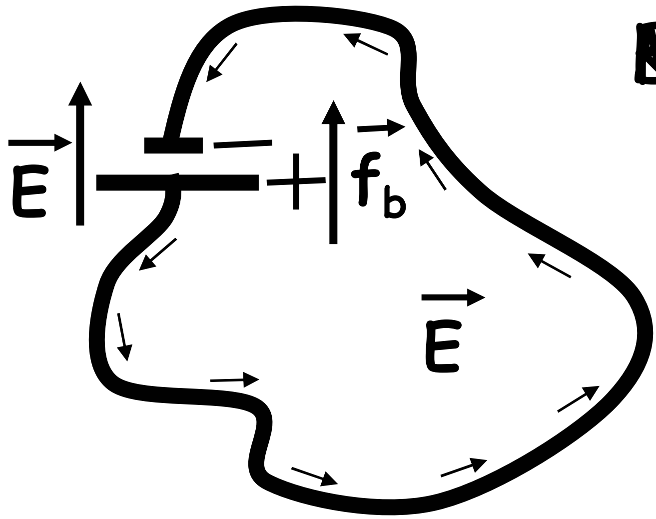
POWER SUPPLIED BY AN EMF SOURCE





Definitie EMK

$$\vec{J} = \sigma \vec{f} \quad \text{met} \quad \vec{f} = \vec{f}_b + \vec{E}$$



Let op:
$\vec{f}_b // \vec{E}$
maar
$\vec{f}_E = -e\vec{E}$

$$\mathcal{E} \equiv \oint_{kring} \vec{f} \cdot d\vec{l} = \oint_{kring} \left(\vec{f}_b + \vec{E}\right) \cdot d\vec{l}$$

$$= \oint_{kring} \vec{f}_b \cdot d\vec{l} + \oint_{kring} \vec{E} \cdot d\vec{l} = \oint_{kring} \vec{f}_b \cdot d\vec{l}$$

(the $\oint_{kring} \vec{E} \cdot d\vec{l}$ term is crossed out) statisch $\Rightarrow 0$

v.b.: voor een kring met:
- batterij met V_0
- constante stroomdichtheid $|\vec{J}| = I/A$

$$\mathcal{E} \equiv \oint_{kring} \vec{f} \cdot d\vec{l} = \oint_{kring} \vec{f}_b \cdot d\vec{l}$$

$$= -\int_{binnen\ batterij!} \vec{E} \cdot d\vec{l} = \int_{buiten\ batterij!} \vec{E} \cdot d\vec{l} \equiv V_0$$

Voor alle duidelijkheid (hoop ik):
- dit is dus een statische opstelling
  $\Rightarrow$ kringintegraal van E is nul
    - klein E-veld in de draad
    - groot (tegengesteld) E-veld in de "batterij"
- **chemie** in batterij pompt elektronen
  tegen het veld in van de + pool naar de – pool $\Rightarrow f_b$

$$\mathcal{E} = \oint_{kring} \frac{\vec{J}}{\sigma} \cdot d\vec{l} = I \oint_{kring} \frac{dl}{\sigma A} \equiv IR$$

$$\Rightarrow R \equiv \oint_{kring} \frac{dl}{\sigma A} \rightarrow \frac{l}{\sigma A}$$

zie hiervoor

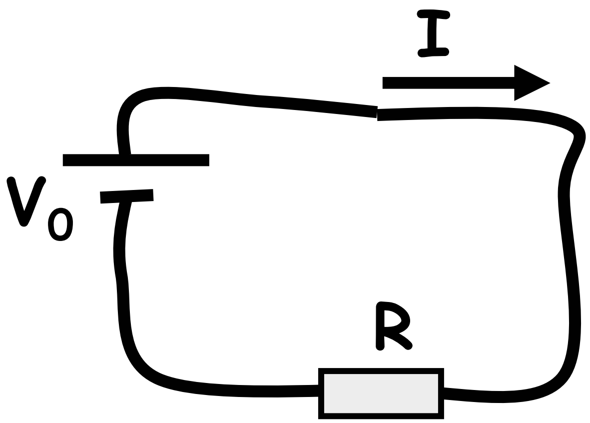
Energie

Dissipatie in een weerstand R

Energie in een capaciteit C

Energie van een elektrische veld configuratie

Dissipatie in weerstand R



Opmerking:
de gedissipeerde energie is "weg" d.w.z. verdwijnt als warmte

De EMK (V_0) pompt iedere seconde I Coulombs rond.
Dat kost werk=energie (batterij raakt leeg!)
Die energie wordt *gedissipeerd* in de weerstand R

Wat is numeriek de energie dissipatie?

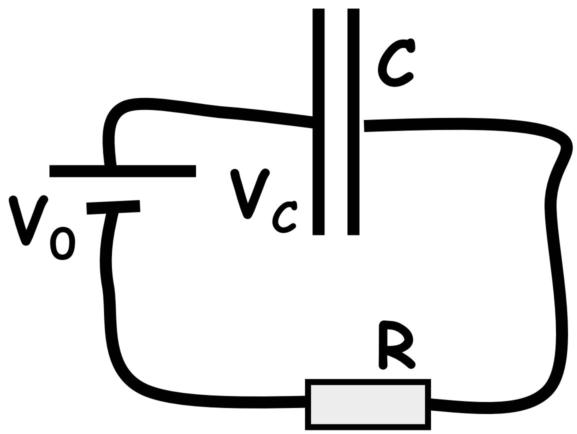
$$P \equiv \text{vermogen} = \frac{\text{energie}}{\text{seconde}}$$

$$= V_0 * \frac{\#\ \text{opgepompte Coulombs}}{\text{seconde}} = V_0 * I = I^2 * R = \frac{V^2}{R}$$

Joule's dissipatie wet

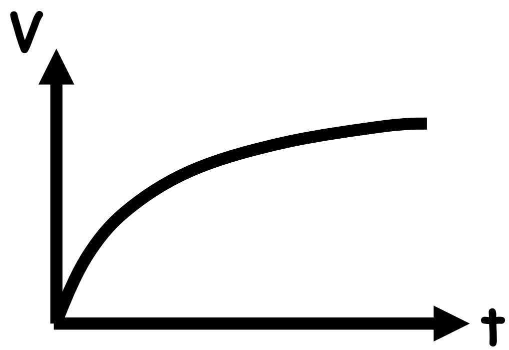
[P]=[VI]
=Volt∗Ampère
≡Watt

Energie in een: capaciteit C



De capaciteit wordt opgeladen:
- warmte ontwikkeling in R "weg"
- opgeladen capaciteit is opgeslagen "energie"

Hoeveel energie is dat?



$$P \equiv \frac{dW}{dt} = V_C(t) * I(t) = \frac{Q_C}{C} * \frac{dQ_C}{dt}$$

$$\Rightarrow U_C = \int_0^\infty \frac{dW}{dt} dt = \int_0^\infty \frac{Q_C}{C} \frac{dQ_C}{dt} dt = \int_0^Q \frac{Q_C}{C} dQ_C = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2} C V^2$$

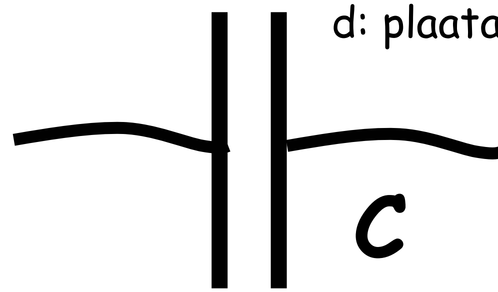
Energie in: E-veld

$$U_{Elektrisch} = \frac{\varepsilon_0}{2} \int_{volume} E^2 dv$$

Enerzijds: $U_C = \frac{1}{2} C V^2$

Anderzijds: $U_C = \frac{\varepsilon_0}{2} \int_{volume} E^2 \mathrm{d}v$

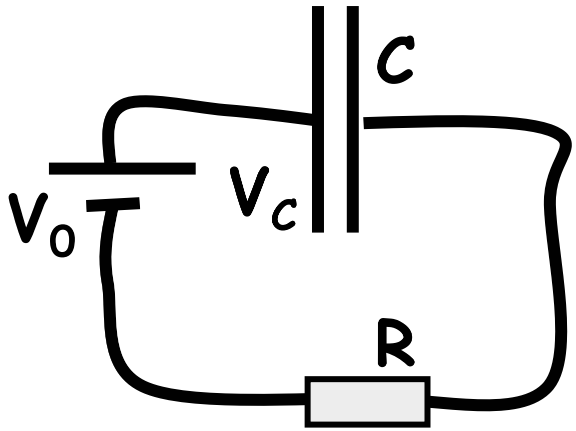
} zelfde?



$$\begin{cases} E = \frac{V}{d} \\ C = \frac{\varepsilon_0 A}{d} \end{cases} \Rightarrow \frac{\varepsilon_0}{2} \int_{volume} E^2 \mathrm{d}v = \frac{\varepsilon_0}{2} \frac{V^2}{d^2} d\,A = \frac{1}{2} C V^2$$

E≠0 in het volume=dA

Gedrag R en C in schakelingen



oplossing voor: $\frac{df}{dt} = af + b$; hoe vind ik f(t)?

los eerst op: $\frac{df}{dt} = af \Rightarrow f(t) = Ae^{at}$

neem dan als "ansatz": $f(t) = A(t)e^{at}$

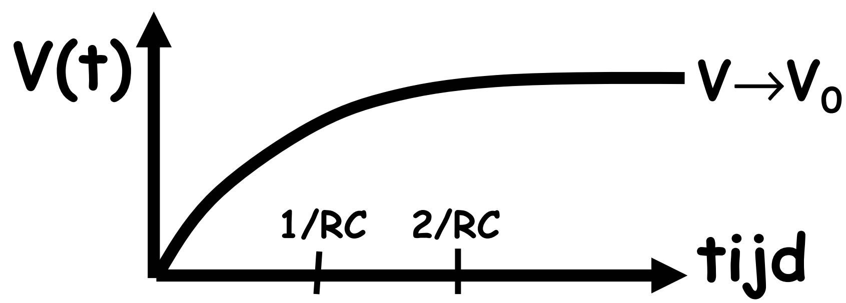
$$\Rightarrow e^{at}\frac{dA}{dt} = b \Rightarrow A(t) = -\frac{b}{a}e^{-at} + A_0 \Rightarrow f(t) = A_0 e^{at} - \frac{b}{a}$$

Beginsituatie $Q_C(0) = V_C(0) = 0$

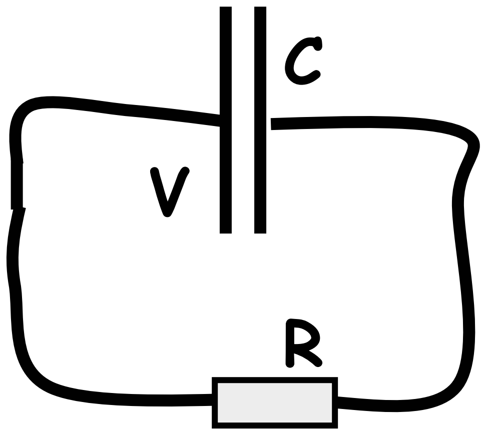
Gevraagd $V_C(t)$

Uitwerking (Ohm EMK = IR):

$$V_0 - V_C = IR = RC\frac{dV_C}{dt} \Rightarrow V_C(t) = V_0\left(1 - e^{-t/RC}\right)$$

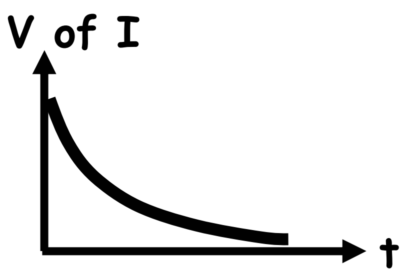


Opgave voor jullie



Na opladen condensator haal je batterij weg.
De lading op condensator neemt exponentieel af.
Bereken gedissipeerde energie in weerstand R.

Moet 0.5 CV^2 geven! Op t=0 geldt: $V_C=V_0$.



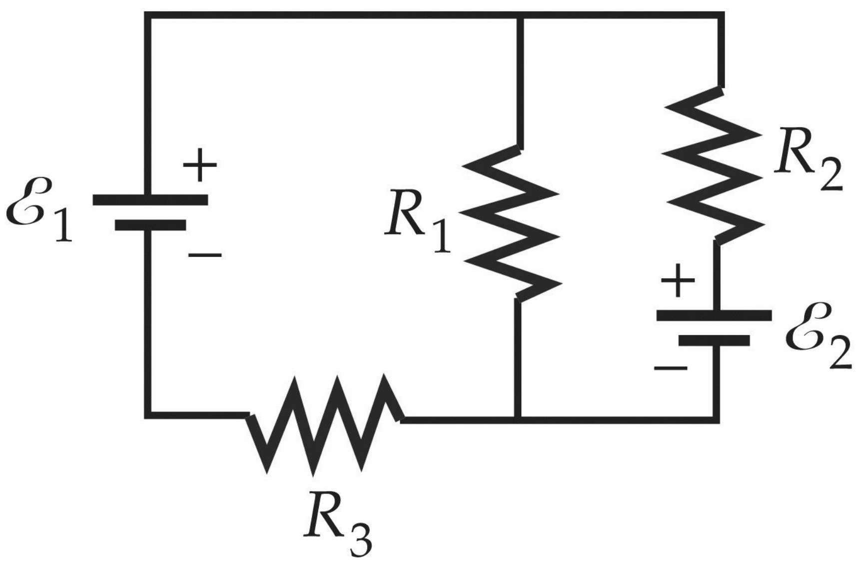
Antwoord : $V(t) = V_0 e^{-t/RC} \Rightarrow$ stroom door R: $I(t) = \frac{V_0}{R} e^{-t/RC}$

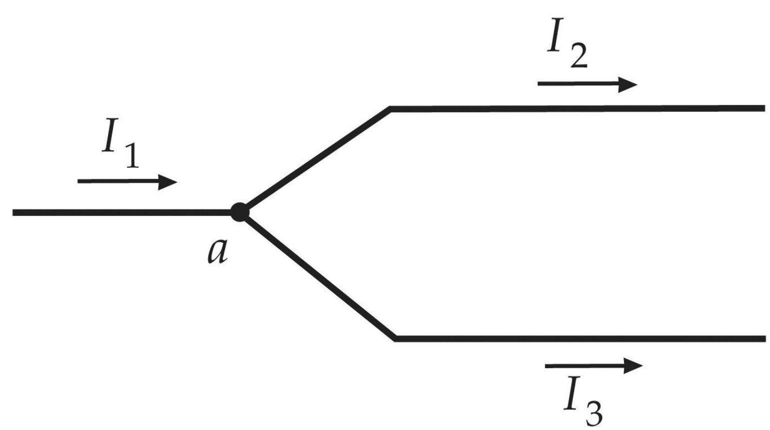
$$\Rightarrow \frac{dW}{dt} \equiv P \equiv VI \rightarrow \frac{V_0^2}{R} e^{-2t/RC} \Rightarrow W = \int_0^\infty \frac{dW}{dt} dt = \int_0^\infty \frac{V_0^2}{R} e^{-2t/RC} dt = \frac{1}{2} C V_0^2$$

Wetten van Kirchhoff

1. When any closed-circuit loop is traversed, the algebraic sum of the changes in potential must equal zero.
2. At any junction (branch point) in a circuit where the current can divide, the sum of the currents into the junction must equal the sum of the currents out of the junction.

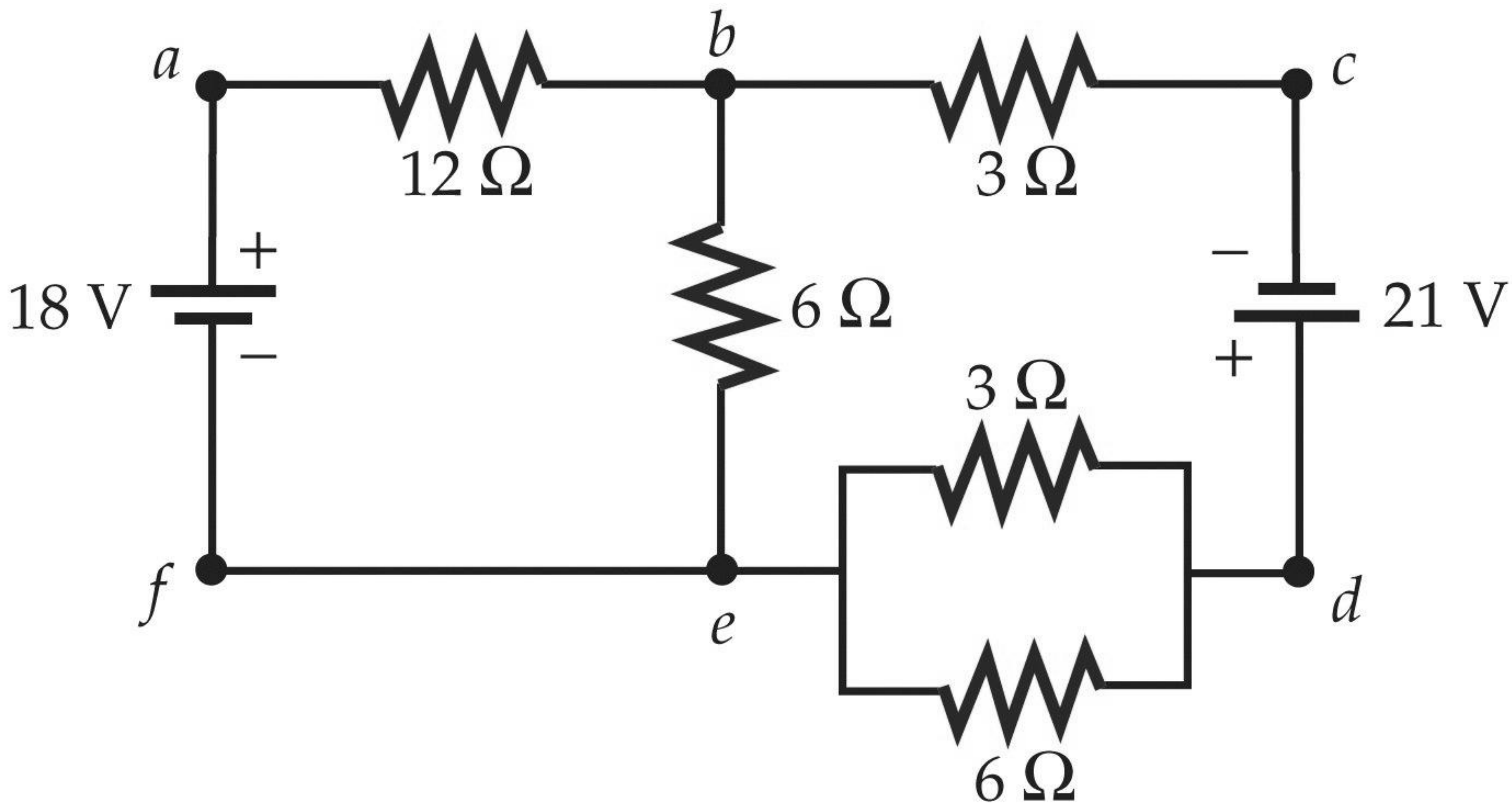
KIRCHHOFF S RULES

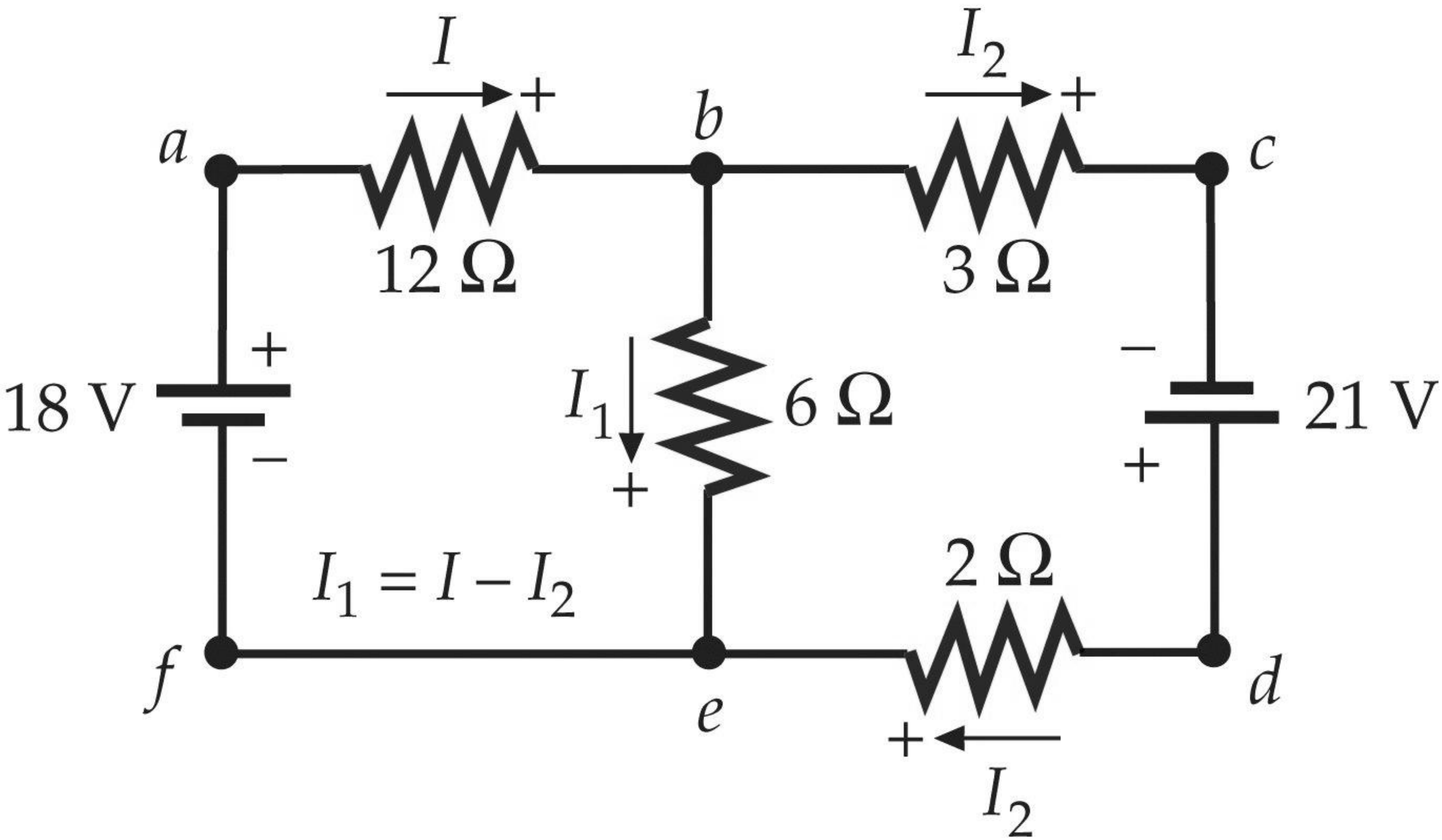


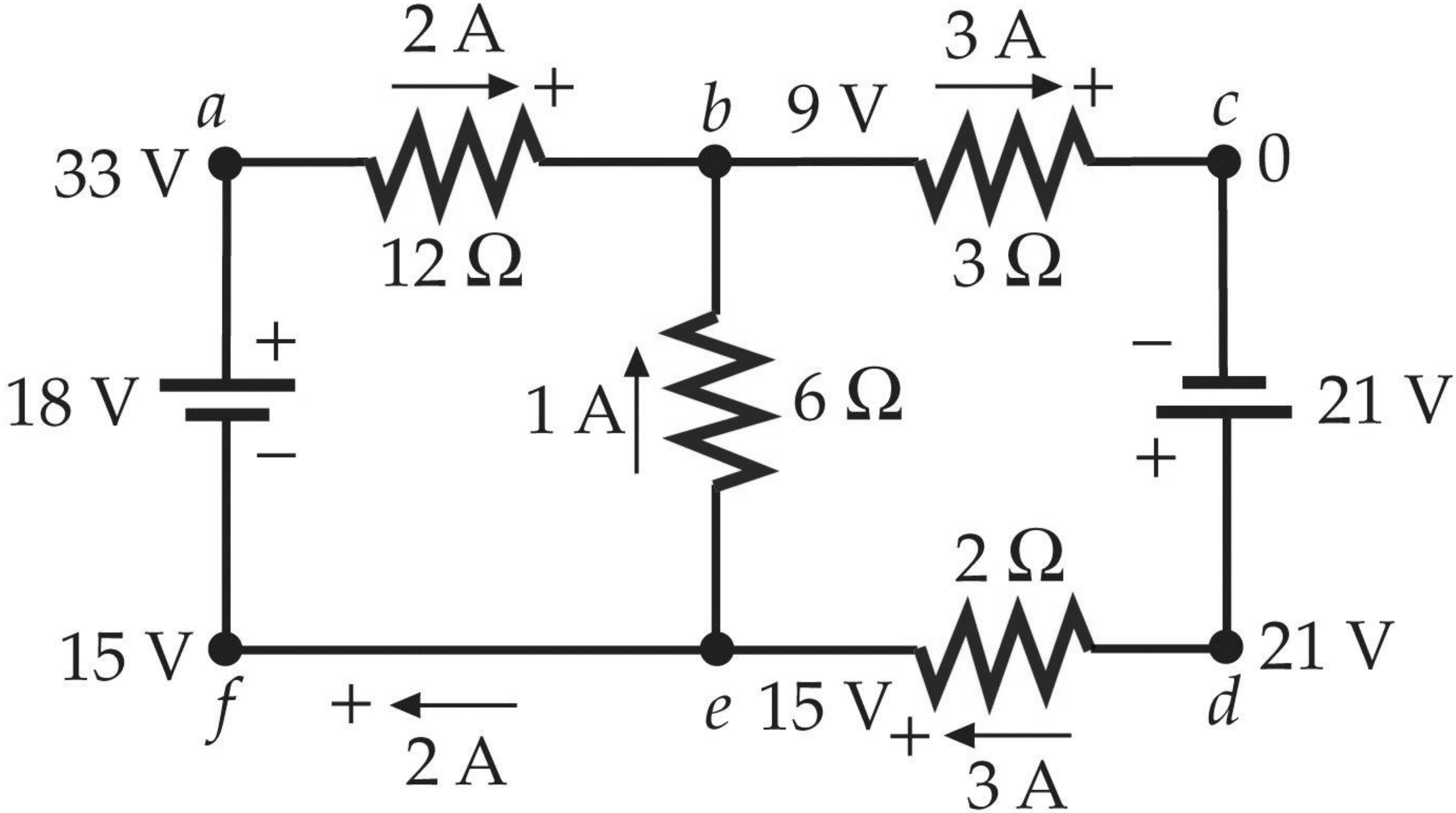


1. Draw a sketch of the circuit.
2. Replace any series or parallel resistor combinations or capacitor combinations by their equivalent values.
3. Choose the positive direction for each branch of the circuit and indicate the positive direction with a direction arrow. Label the current in each branch. Add plus and minus signs to indicate the high-potential terminal and low-potential terminal of each source of emf.
4. Apply the junction rule to all but one of the branch points (junctions).
5. Apply the loop rule to each loop until you obtain as many independent equations as there are unknowns. When traversing a resistor in the positive direction, the change in potential equals $-IR$. When traversing a battery from the negative terminal to the positive terminal, the change in potential equals $\mathcal{E} - IR$.
6. Solve the equations to obtain the desired values.
7. Check your results by assigning a potential of zero to one point in the circuit and use the values of the currents found to determine the potentials at other points in the circuit.

GENERAL METHOD FOR ANALYZING MULTILOOP CIRCUITS


a
b
c
12 Ω
3 Ω
+
18 V
−
6 Ω
−
21 V
+
3 Ω
f
e
d
6 Ω


I
I2
a
b
c
12 Ω
3 Ω
18 V
I1
6 Ω
21 V
I1 = I − I2
2 Ω
f
e
d
I2


2 A
3 A
a
b
9 V
c
33 V
0
12 Ω
3 Ω
18 V
1 A
6 Ω
21 V
2 Ω
15 V
21 V
f
e
15 V
d
2 A
3 A