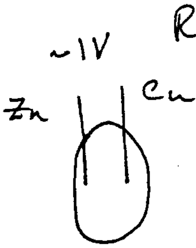
BATTERIES — ELECTROMOTIVE

A battery is a SOURCE of potential difference (It can be thought of as a way of carrying charge uphill)



Remember the toy POTATO BATTERY using a strip of copper, a strip of zinc + a potato?

Almost any two metals placed in a common electrolyte usually acid solution will create a p.d. depending upon the ease with which the metal gives up or takes on an electron

ELECTROMOTIVE SERIES

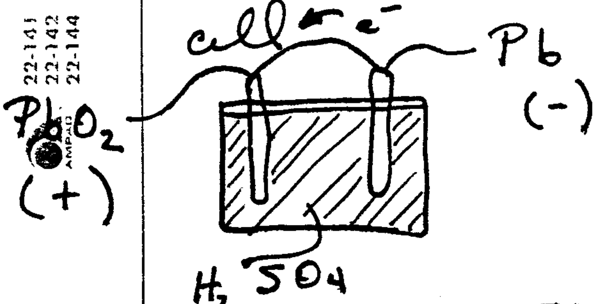
ACCEPTS e^-

Li	LITHIUM	-3.0 ✓
K	POTASSIUM	-2.9 ✓
Zn	ZINC	-0.76
Cd	CADMIUM	-0.40
Ni	NICKEL	-0.25
Pb	LEAD	-0.13
Cu	COPPER	$+0.34$
Ag	SILVER	$+0.8$
Au	GOLD	$+1.3$

DONATES e^-

EMF

Up until this time we have introduced sources of potential difference w/o being concerned about the characteristics of the "source" itself. Let's consider an automobile battery - lead-acid storage cell



1) at negative electrode

$$Pb + SO_4^{--} \rightarrow PbSO_4 + 2e^-$$

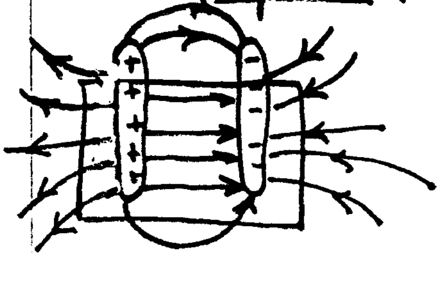
2) at the positive electrode

$$PbO_2 + 4H^+ + SO_4^{--} + 2e^- \rightarrow PbSO_4 + 2H_2O$$

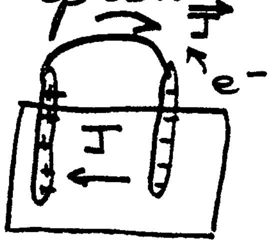
Overall

$$Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$$

When the cell is isolated w/o anything connecting terminals (we say the circuit is <u>open</u>) it still maintains one terminal at a higher electric potential (the + terminal) than the other terminal (the − terminal)



If we add a connecting wire charge flows around the circuit and a current is established.



Inside the cell + charge is transported from the − terminal to the + terminal and vice versa. These directions of charge transport are opposite to the way that charges would flow on purely electrical grounds. In the absence of connection between pos + neg terminals charges do not move implying that ∃ a force counteracting the electrostatic force or an "equivalent" nonelectrostatic field

$$\vec{E} = \vec{E}_n + \vec{E}_e = 0 \qquad \vec{E}_n = -\vec{E}_e$$

$$\oint E_{\parallel}\, ds = 0$$

$$\oint_{cell} E_{\parallel}\, ds = \int E_n\, dl = V_{ab} = \mathcal{E}$$

work performed

"ELECTROMOTIVE POTENTIAL

chgs in sol'n to flow

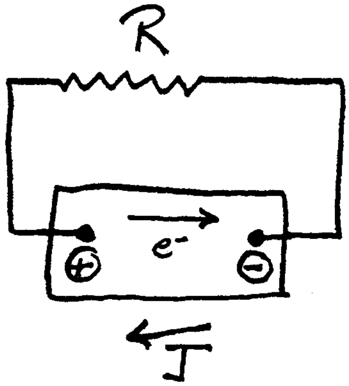
net chg on terminals would be neutralized $\Rightarrow V_{ab} \to 0$. In this case

$$\boxed{\mathcal{E} = V_{ab}}$$

OPEN CIRCUIT

CLOSED CIRCUIT

Internal resistance $\Rightarrow$ chgs do not flow freely through source. To maintain V_{ab} must maintain chg. on terminals, chgs must flow through source. Source must perform work to move electrons from



$$\boxed{V_{ab} = \mathcal{E} - Ir = IR}$$

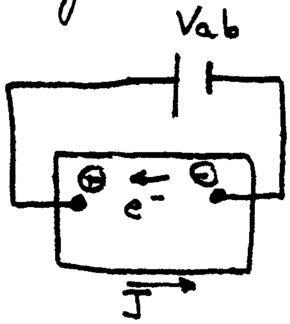
$$I = \frac{\mathcal{E}}{R + r}$$

current in source from - to +

In general for any number of sources, resistances internal + external

$$I = \frac{\Sigma \mathcal{E}}{\Sigma R}$$

If connected to external circuit containing other sources can possibly get current $\vec{J}$ from + to −



(p.d. applied externally greater than source emf ⇒ source charges)

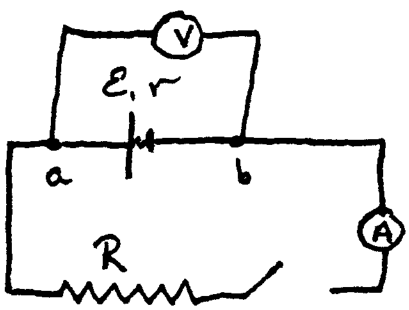
$$V_{ab} = \mathcal{E} + Ir$$

Measure current, voltage w/ meters

Ⓐ Ⓥ ammeter, voltmeter

$\mathcal{E} = 12\ V \qquad r = 2\ \Omega$

$R = 4\ \Omega$



Circuit open

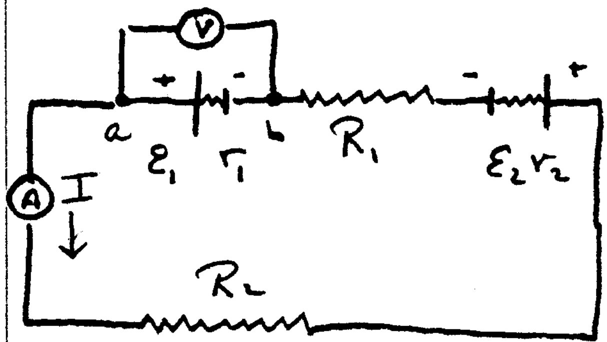
$V_{ab} = 12\ V$ measured

Switch closed, p.d. causes current to flow:

$$I = \frac{\mathcal{E}}{R+r} = \frac{12\ V}{4\ \Omega + 2\ \Omega} = 2\ A$$

$$V_{ab} = IR = 2A \cdot 4\ \Omega = 8\ V$$

$$= \mathcal{E} - Ir = 12V - 2\ \Omega \cdot 2A = 8\ V$$



Must define direction of positive current – can take our pick, but must be consistent. Then emf is positive if nonelectrostatic force in direction of current.

<u>$\mathcal{E}$ positive if I from – to +</u>

$$I = \frac{\Sigma \mathcal{E}}{\Sigma R} = \frac{\mathcal{E}_1 - \mathcal{E}_2}{r_1 + r_2 + R_1 + R_2}$$

measured by ammeter

$$V_{ab} = \mathcal{E}_1 - I r_1 = I\,(R_1 + r_2 + R_2)$$

p.d. across source 1 — p.d. around remainder of circuit

measured by voltmeter

Car battery: 12 V emf causes current I to flow through system when ignition turned on performs work starting car

$$V_{ab} = \mathcal{E} - I r = 12\,V - I$$

car engine runs generator (alternator)

which generates $V_{ab} > 12$ V

$$V_{ab} = \mathcal{E} + Ir$$

recharges car battery. What happens when car battery goes bad?
$\mathcal{E}$ relatively const but $r \to$ up
battery won't charge. If you take a battery in to svc. station they check voltage on open circuit

$$V_{ab} = \underline{\underline{\mathcal{E}}} \quad \text{checking emf}$$

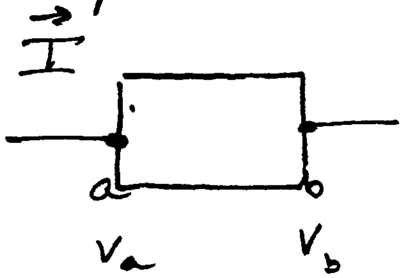
then test "under load"

$$V_{ab} = \mathcal{E} - Ir \quad \text{checking } r$$

Car hard to start when cold due to $r = r(T)$ such that r high when T low.

WORK AND POWER

V_{ab} recall is potential energy difference per unit charge, thus



if we move charge ΔQ through p.d. V_{ab} we have performed work

$$\Delta W = \Delta E_p = \Delta Q \, (V_a - V_b)$$

If we have current $I = \frac{\Delta Q}{\Delta t}$

then $\Delta Q = I \Delta t$

$$\Delta W = V_{ab} I \Delta t$$

Source of p.d. transfers energy to circuit between a and b at a rate

$$P = \frac{\Delta W}{\Delta t} = \frac{V_{ab} I \Delta t}{\Delta t}$$

$$\boxed{P = VI} \quad \text{Power}$$

If $V_a > V_b$ energy transferred into circuit

$V_b > V_a$ charge gains energy at expense of some other form in circuit

$$P = V \cdot I$$

$$1 \text{ WATT} = (1V)(1A) = (1 J C^{-1})(1 C s^{-1}) = 1 J s^{-1} = 1 W$$

100 W light bulb - power rating is rate of power consumption of bulb (unfortunately not rate of output of radiant energy). 115 V household voltage $\Longrightarrow$

$$100 W = 115 V \cdot I$$

$$I = \frac{100 W}{115 V} = 0.87 A$$

current flowing.