Which is the Anode??

GUILTY PARTIES

Michael Faraday

Anode is where current flows "into" an electrolytic cell. When the *internal* current goes in same direction as current loop providing Earth's magnetic field, anode is on the **east** side.[1]

Benjamin Franklin

Silk on glass: "vitreous electricity" = positive

Fur on amber: "resinous electricity" = negative

xkcd.com/567

BENJAMIN FRANKLIN?   YES?
I BRING A MESSAGE FROM THE FUTURE! I DON'T HAVE MUCH TIME.   WHAT IS IT?
THE CONVENTION YOU'RE SETTING FOR ELECTRIC CHARGE IS BACKWARD. THE ONE LEFT ON GLASS BY SILK SHOULD BE THE *NEGATIVE* CHARGE.

WE WERE GOING TO USE THE TIME MACHINE TO PREVENT THE ROBOT APOCALYPSE, BUT THE GUY WHO BUILT IT WAS AN ELECTRICAL ENGINEER.

1. M. Faraday, "Experimental Researches in Electricity, Seventh Series." *Philosophical Transactions of the Royal Society* **1834** *124* (1): 77. Note that the North Pole is the *south* pole of earth's magnet.
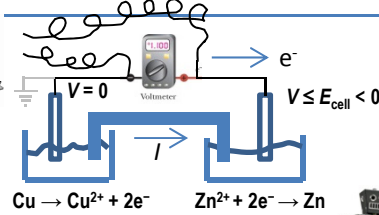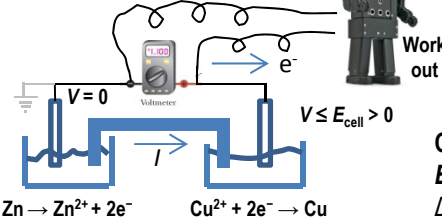
CHARGING BATTERY / ELECTROLYTIC CELL

Work in

Anode: oxidation takes place
Current flows into cell

$Cu \rightarrow Cu^{2+} + 2e^-$ $Zn^{2+} + 2e^- \rightarrow Zn$

V = 0 e^- $V \leq E_{cell} < 0$

I

+ AA −

Cathode: reduction takes place on the **right**
$E = E_{red}(right) - E_{red}(left) < 0$
$\Delta G > 0$ for net reaction

DISCHARGING BATTERY

Anode: oxidation takes place
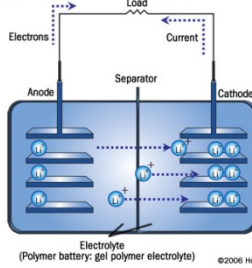Current flows into cell

Anode marked "−" on battery package

V = 0 e^- Work out

I

$Zn \rightarrow Zn^{2+} + 2e^-$ $Cu^{2+} + 2e^- \rightarrow Cu$

$V = E_{cell}$ when no current flowing
− +

− AA +

Cathode: reduction takes place on the **right**
$E = E_{red}(right) - E_{red}(left) > 0$
$\Delta G < 0$ for net reaction

LI-ION BATTERIES

Electrodes named according to role in **discharge** cycle

Anode material hosts Li in charged state
Lithium batteries (primary): Li metal
Li-ion batteries (secondary = rechargeable): Li:C, Li:Si

Load   Electrons   Current
Anode   Separator   Cathode
Electrolyte (Polymer battery: gel polymer electrolyte)   ©2006 HowStuffWorks

Cathode material hosts Li in **discharged** state
$Fe(PO_4):Li$, Li_2S, etc

During discharge:
Li ions move from anode to cathode through separator
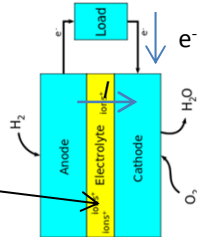Electrons move from anode to cathode through circuit

http://en.wikipedia.org/wiki/Lithium-ion_battery

FUEL CELL

Anode: fuel is oxidized

e.g.: H_2 oxidized to H_2O
Pt catalyst on porous carbon

Electrolyte (solid oxide, proton-exchange membrane)

Load e^- H_2O H_2 Anode   Electrolyte   Cathode O_2
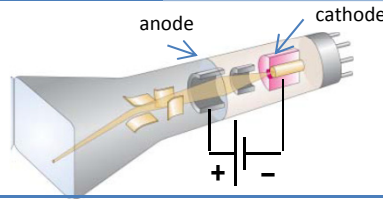
Cathode: oxygen is **reduced** (e.g. to H_2O)

Oxygen reduction catalysts typically less efficient
$E = E_{red}(right) - E_{red}(left) > 0$
$\Delta G < 0$ for net reaction

http://en.wikipedia.org/wiki/Fuel_cell

CATHODE-RAY TUBE

Anode: current flows into device from external circuit

Anode is "positive" terminal

anode   cathode
+   −

Cathode: current flows out of device ("negative" terminal)

Cathode ray (electron beam) is *emitted* from the cathode, typically a heated metal filament

http://wps.aw.com/wps/media/objects/877/898586/topics/topic07.pdf

SCHOTTKY DIODE (rectifying metal-semiconductor contact)

Anode: where current flows into device in *"forward"* (highly conducting) direction

Anode   Cathode

Cathode: where current flows out of device in "forward" direction – tip of the arrow in symbol

http://en.wikipedia.org/wiki/Schottky_diode

Typically anode is a high-workfunction metal like Pt, W, Cr and cathode is an *n*-type semiconductor crystal such as galena (PbS).

P-N JUNCTION DIODE

Anode: where current flows into device in *"forward"* (highly conducting) direction

anode *p*-type semiconductor   I   cathode *n*-type semiconductor
+   −

Even when device is typically *used* with current flowing in "reverse" direction (PV, Zener).

http://en.wikipedia.org/wiki/Zener_diode
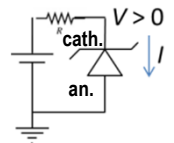http://photonicswiki.org/index.php?title=Physics_of_Solar_Cells

V = 0   I = 0   an.   cath.
V > 0   I   an.   cath.
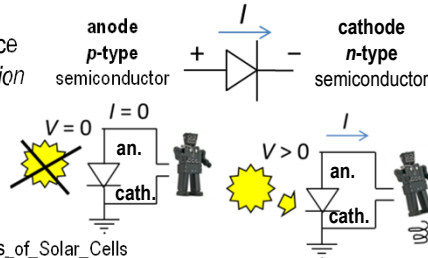
Cathode: where current flows out of device in "forward" direction – tip of the arrow in symbol

p-n junction photovoltaic (solar cell):
Forward voltage, but reverse current
*p*-type is still "anode"

Zener diode
Current and voltage reversed; operates at breakdown

V > 0   cath.   an.   I

DYE-SENSITIZED SOLAR CELL

Anode: where current flows into device **under illumination** (opposite of *p-n* junction solar cell).

Anode typically TiO_2; collects electrons from photoexcited dye. Naming convention follows electrolytic cells because hole conductor is **oxidized**.

TCO   dye   Pt
e^-
anode   I   cathode
TiO_2 hole conductor
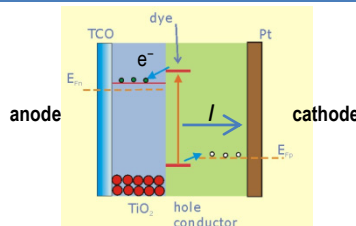
Cathode: where current flows out of device under illumination (electrons go in)

Cathode typically metal (e.g. Pt) electrode that *reduces* hole conductor.

1. M. Grätzel, "Photoelectrochemical cells." *Nature* **2001** *v414* p338.
2. E. Bequerel. *C.R. Acad. Sci.* **1839** *v9*, p145.

THIN FILM SOLAR CELL

Follows p-n junction convention.

Anode: where current flows out of device under illumination. Collects "holes" from active layer.

Al (or Ca/Ag)   Active layer V_2O_5 ITO   Glass substrate

Al   P3HT PCBM V_2O_5 ITO
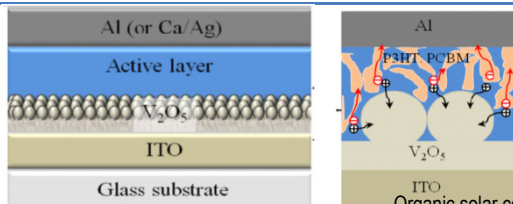
Cathode: where current flows into device under illumination: collects electrons from active layer.

Organic solar cells: Wang et al., *Organic Electronics*, **2012** *v13* (12) p3014.
CdTe & related inorganic: Spies et al., *Solar Energy Materials & Solar Cells* **2009** *v93* p1296.