PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 24100

Electricity & Optics

Lecture 12 – Chapter 25 sec. 6, 26 sec. 1

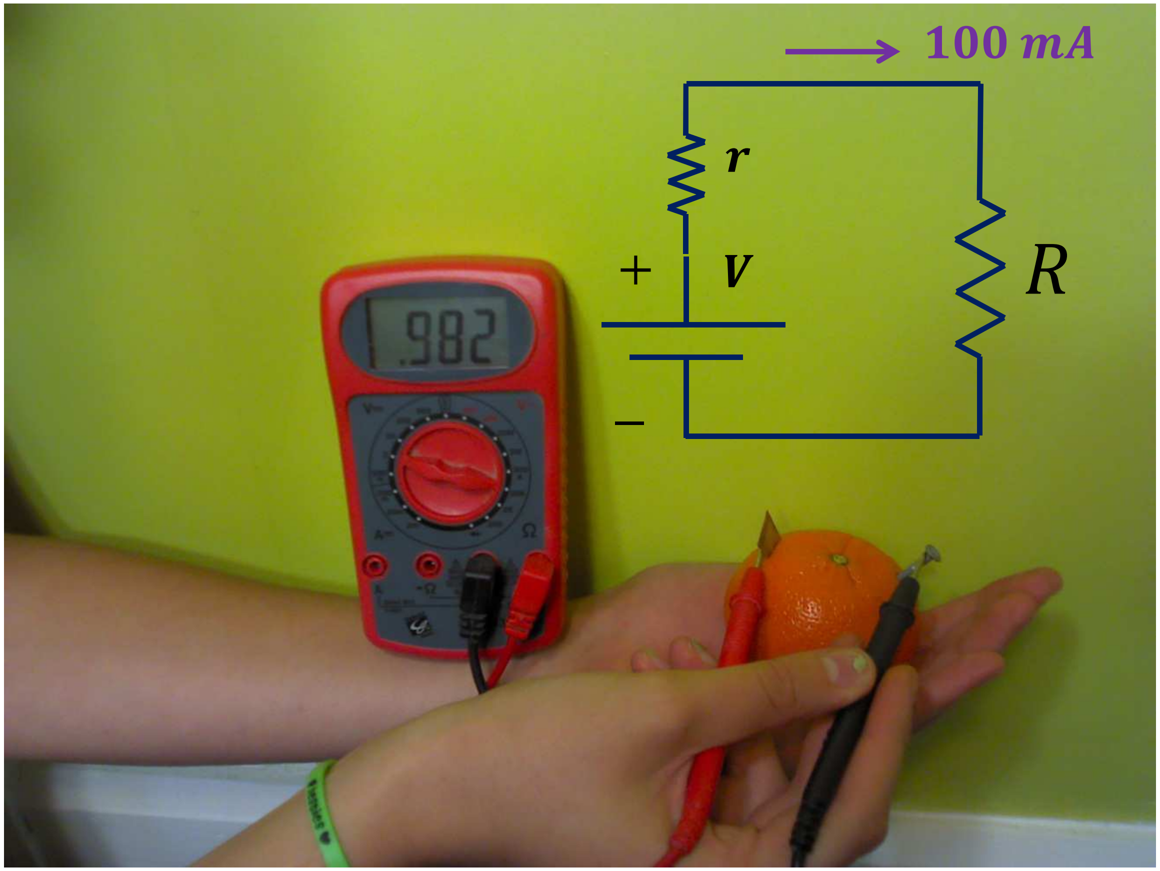
Fall 2012 Semester

Matthew Jones

Question

When there is no load, the orange provides 0.982 Volts.

What is the internal resistance of the orange if the voltage drops to 0.082 volts when the current is 100 mA?



(a) 9 Ω

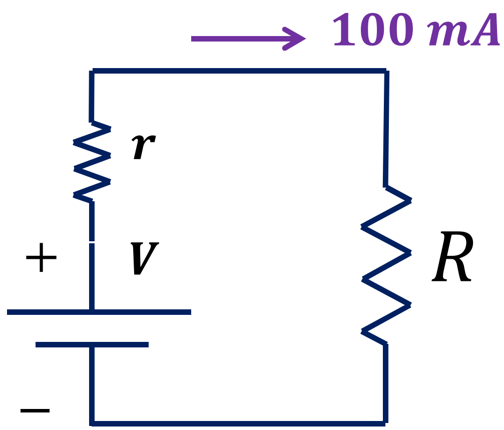
(b) 90 Ω

(c) 0.9 Ω

(d) 10 Ω

(e) not enough information

Internal Resistance



The ideal voltage source produces a potential difference of $0.982\ V$.

When $I = 100\ mA$, the potential difference across R is $\Delta V = 0.082\ V$.

- Kirchhoff's Loop Rule:

$$V - I\,r - \Delta V = 0$$

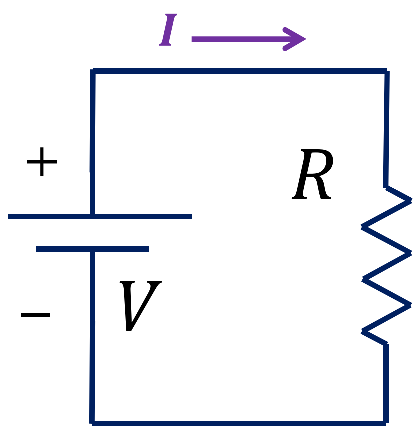
$$r = \frac{V - \Delta V}{I} = \frac{0.9\ V}{0.1\ A} = 9\ \Omega$$

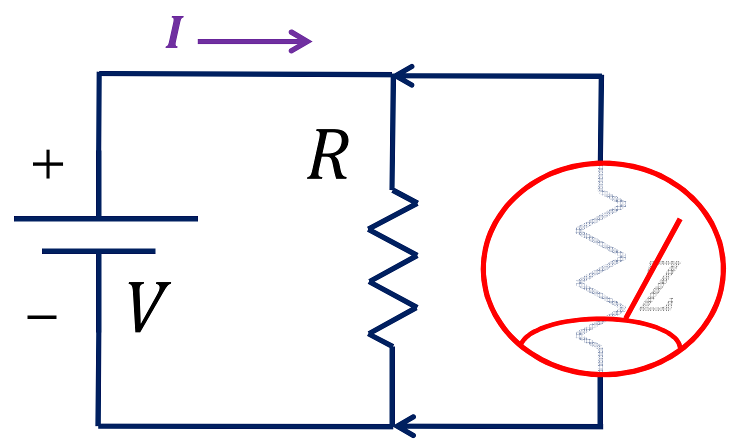
Measuring Current and Voltage

- An ideal voltmeter should measure potential difference in a circuit *without affecting the operation of the circuit*.
- An ideal ammeter should measure the current through part of a circuit *without affecting the operation of the circuit*.

Measuring Voltage

- A volt meter must have a large resistance:



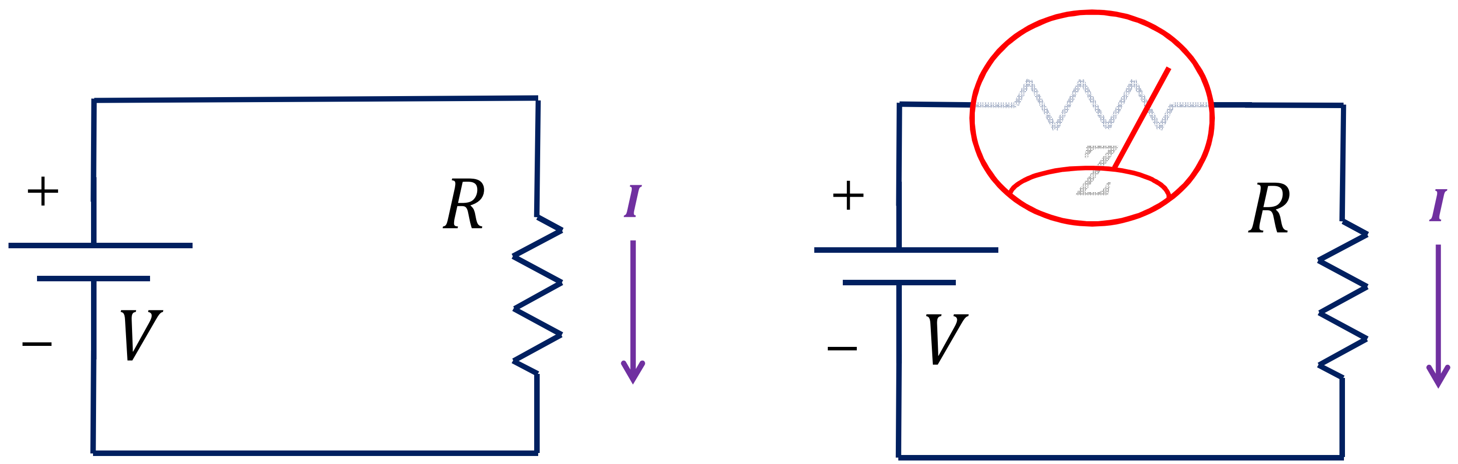


- The current, I is unchanged only when

$$\left(\frac{1}{R}+\frac{1}{Z}\right)^{-1} \approx R \quad \rightarrow \quad Z \gg R$$

Measuring Current

- An ammeter must be placed in series with the current to be measured
- It should must have a small resistance



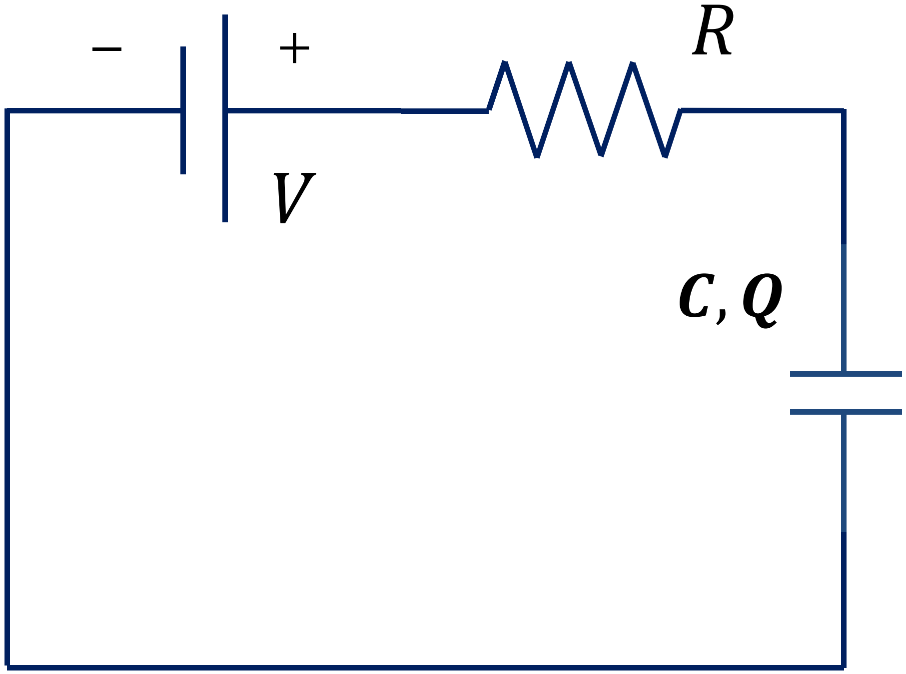
- The current is unchanged when

$$Z + R \approx R \rightarrow Z \ll R$$

Circuits With Capacitors

$$Q = C\,\Delta V$$

$$\Delta V = \frac{Q}{C}$$



Kirchhoff's Loop Rule:

$$V - I\,R - \Delta V = 0$$

$$V - I\,R - \frac{Q}{C} = 0$$

But if $I \neq 0$ then Q will increase or decrease.

Q is a function of time.

Charge on a Capacitor

- The net charge on a capacitor is the sum of all charges that have been collected on the plates:

$$Q(t) = Q_0 + \int_0^t I(t)dt$$

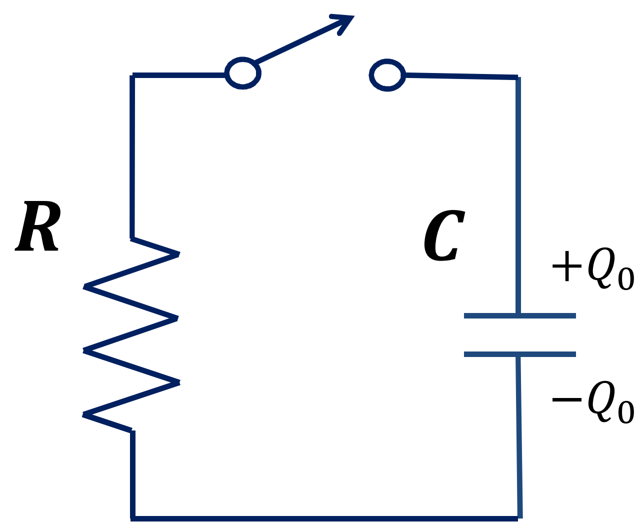
- Fundamental Theorem of Calculus:

$$\frac{dQ}{dt} = I(t)$$

- In circuits with capacitors, we need to specify the initial conditions.

RC Circuits

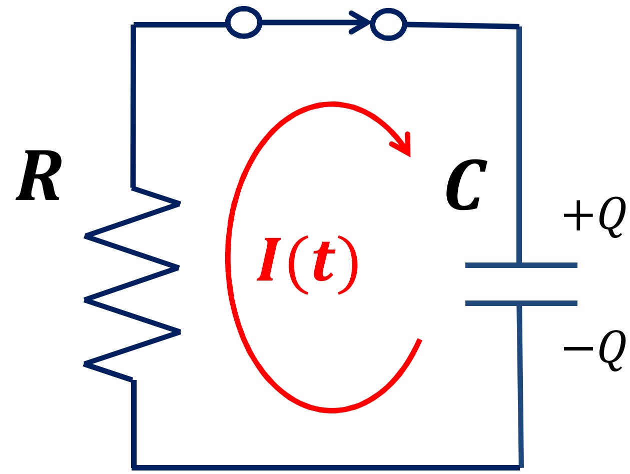
- When $t < 0$, the switch is open.
- The capacitor has an initial charge Q_0 as indicated.
- How will Q change with time after the switch is closed at $t = 0$?



RC Circuits

- Kirchhoff's Loop Rule:

$$-I(t)\,R - \frac{Q(t)}{C} = 0$$



- Differentiate…

$$R\frac{dI}{dt} + \frac{1}{C}I(t) = 0$$

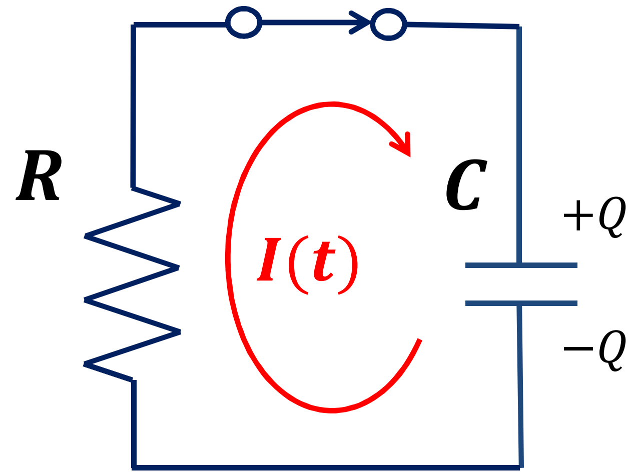
$$\frac{dI}{dt} = -\frac{I(t)}{RC}$$

This reminds you that I is not constant… it is a function of t.

- This is a differential equation…

RC Circuits

- How to solve $\frac{dI}{dt} = -\frac{I(t)}{RC}$?
- Solve by integration:



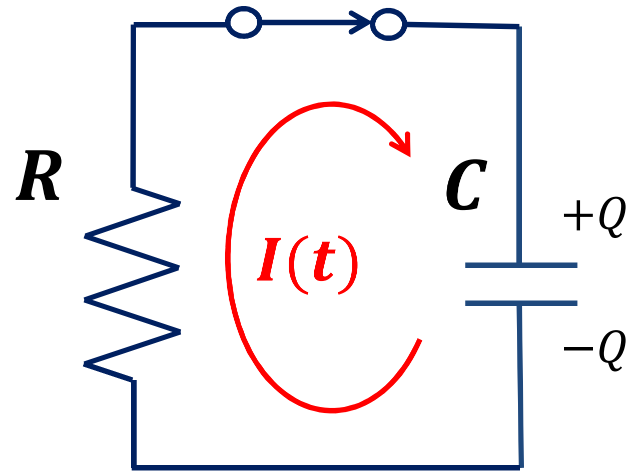
$$\frac{1}{I(t)}\frac{dI}{dt} = -\frac{1}{RC}$$

$$\int_0^t \frac{dI}{I} = -\frac{1}{RC}\int_0^t dt$$

$$\log\left(\frac{I(t)}{I_0}\right) = -\frac{t}{RC}$$

RC Circuits

$$\log\left(\frac{I(t)}{I_0}\right) = -\frac{t}{RC}$$



- Exponentiate both sides:

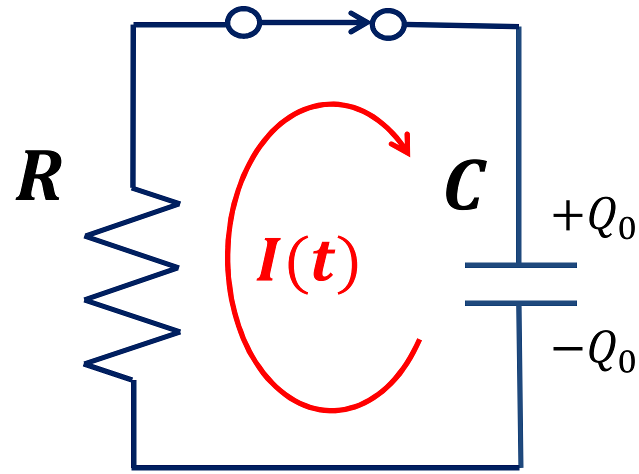
$$I(t) = I_0 e^{-t/RC}$$

- As with all first order differential equations, we have one constant of integration (I_0) that must be determined from the initial conditions.

RC Circuits

$$-I_0\,R\ -\frac{Q_0}{C}=0$$

$$I_0=-\frac{Q_0}{RC}$$



- Complete solution:

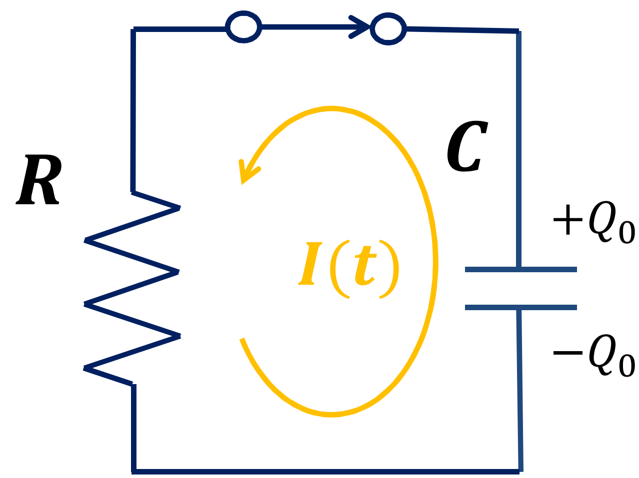
$$I(t)=-\frac{Q_0}{RC}e^{-t/RC}$$

- The negative sign means the current flows opposite the direction we assumed for the arrow.

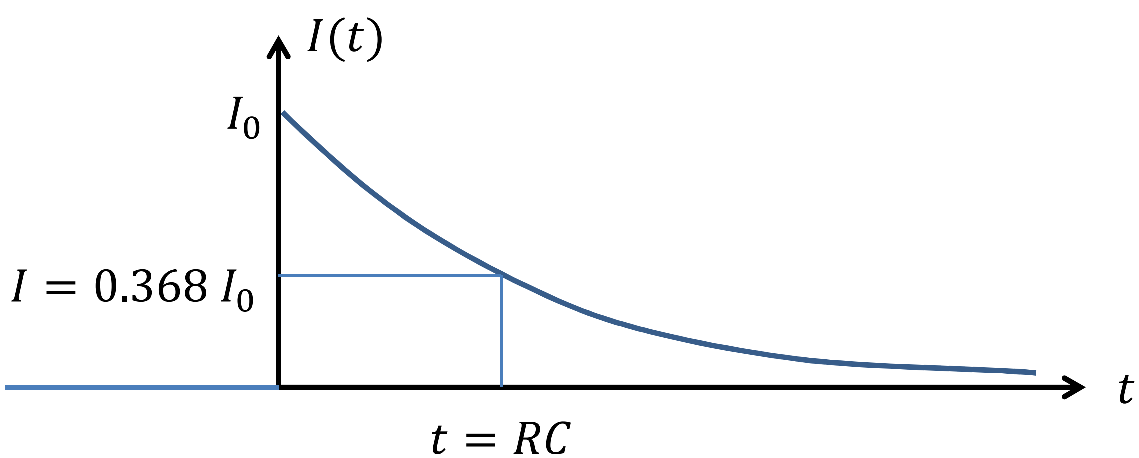
RC Circuits

- Reverse the arrow:

$$I(t) = \frac{Q_0}{RC} e^{-t/RC}$$

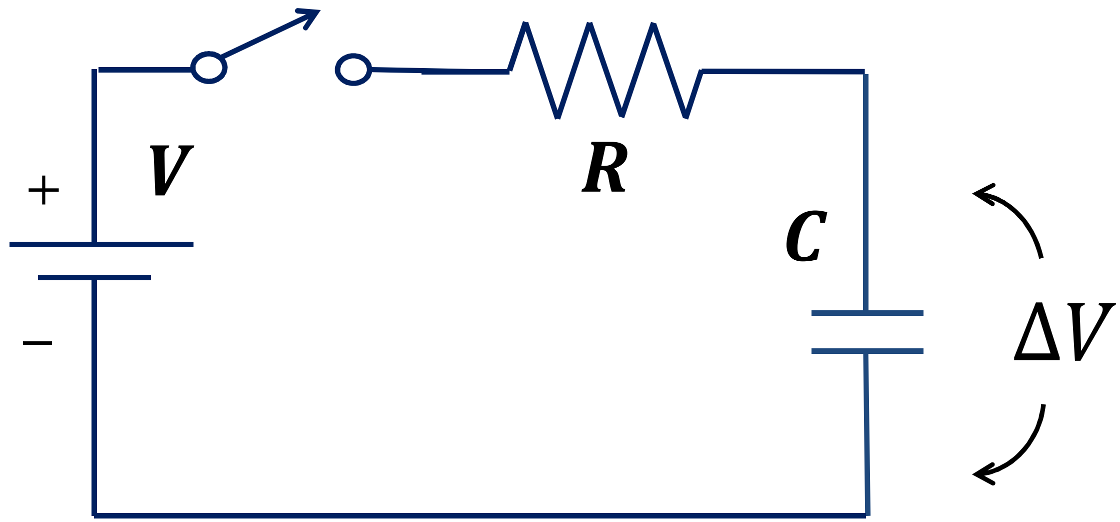


- This makes sense because current will flow in the direction of decreasing electric potential.



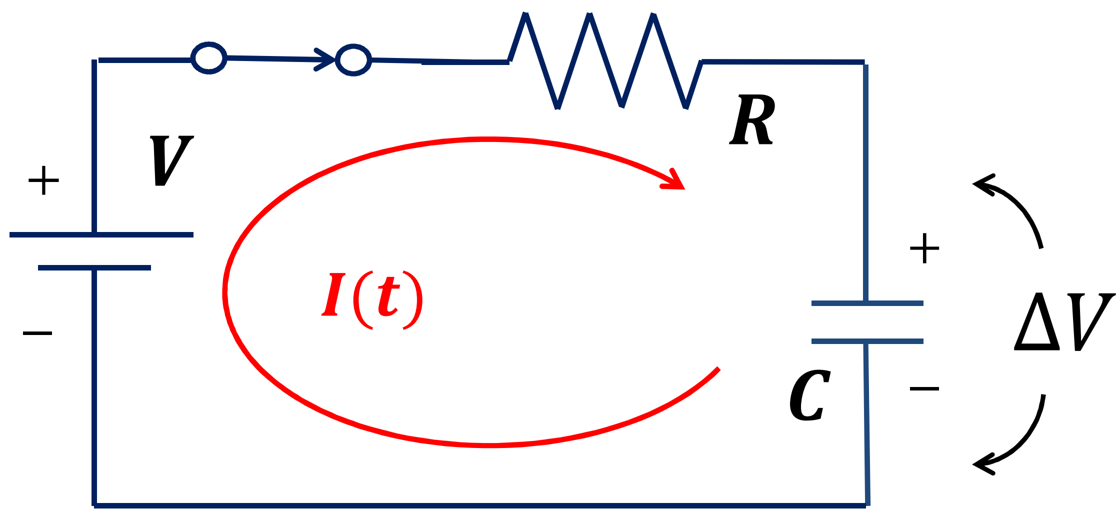
The capacitor initially acts like a ***voltage source*** but eventually acts like an ***open circuit***.

Charging a Capacitor



- Suppose the capacitor is initially uncharged when the switch is open.
- The switch is closed at time $t = 0$.
- What is the potential difference across the capacitor as a function of time?

Charging a Capacitor



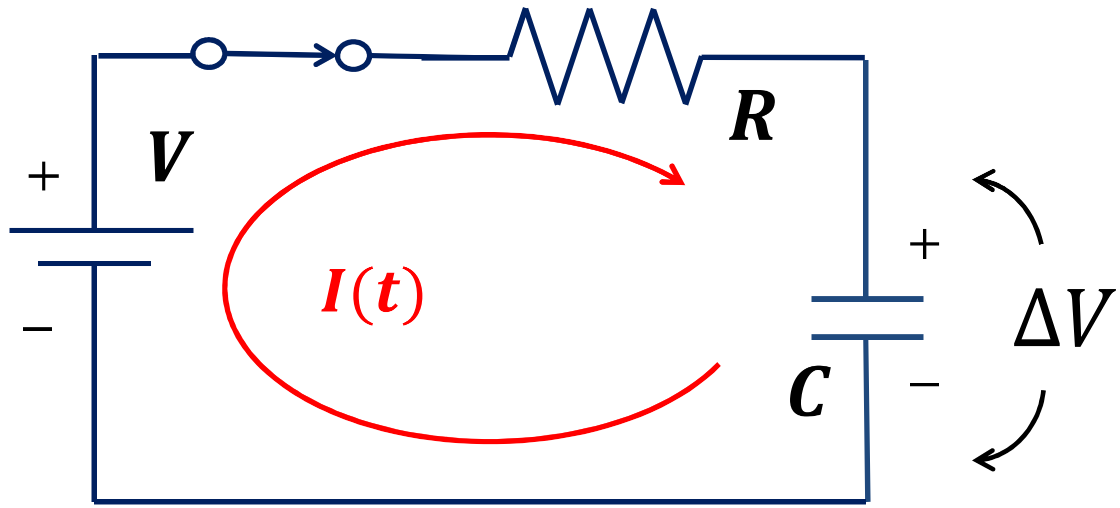
- Kirchhoff's Loop Rule:

$$V - I(t)R - \frac{Q}{C} = 0$$

- Differentiate: $R\frac{dI}{dt} + \frac{I(t)}{C} = 0$

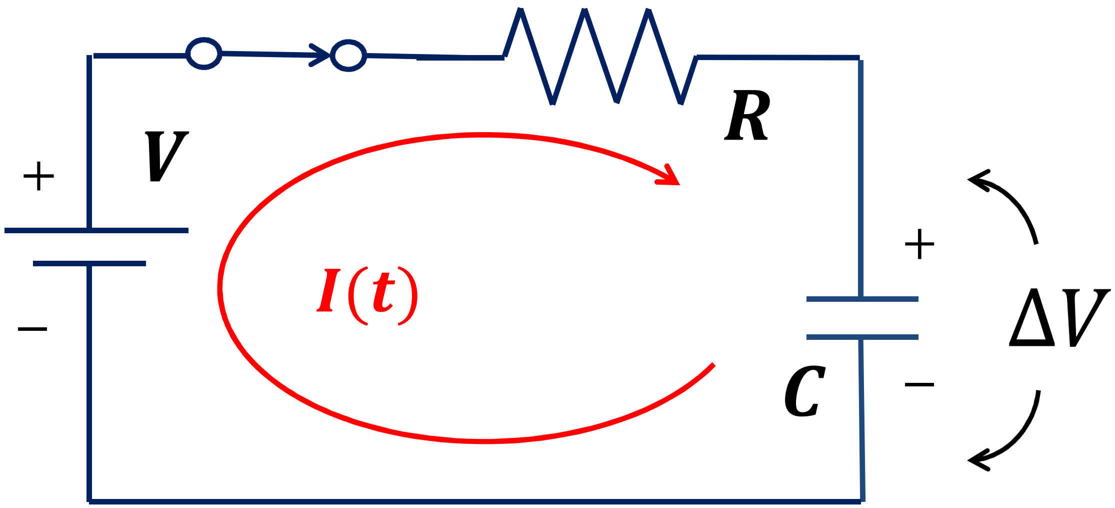
Same as before…

Charging a Capacitor



- General solution: $I(t) = I_0 e^{-t/RC}$
- What's different this time? The initial condition...
- At $t = 0$, the capacitor is uncharged so $\Delta V = 0$ and the initial current is $I_0 = V/R$.

Charging a Capacitor

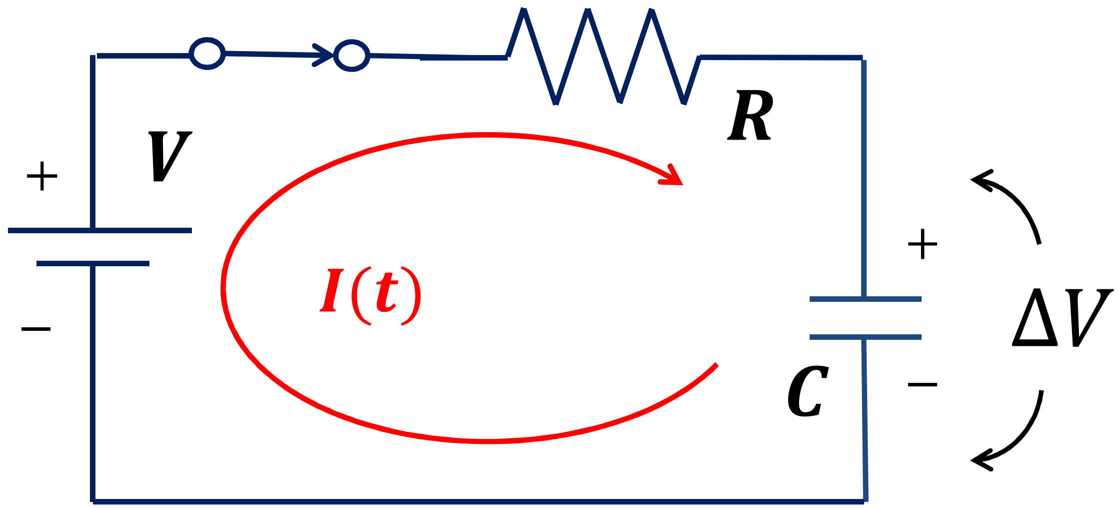


- Solution for the current: $I(t) = \frac{V}{R} e^{-t/RC}$
- But what is ΔV? Use Kirchhoff's Loop Rule:

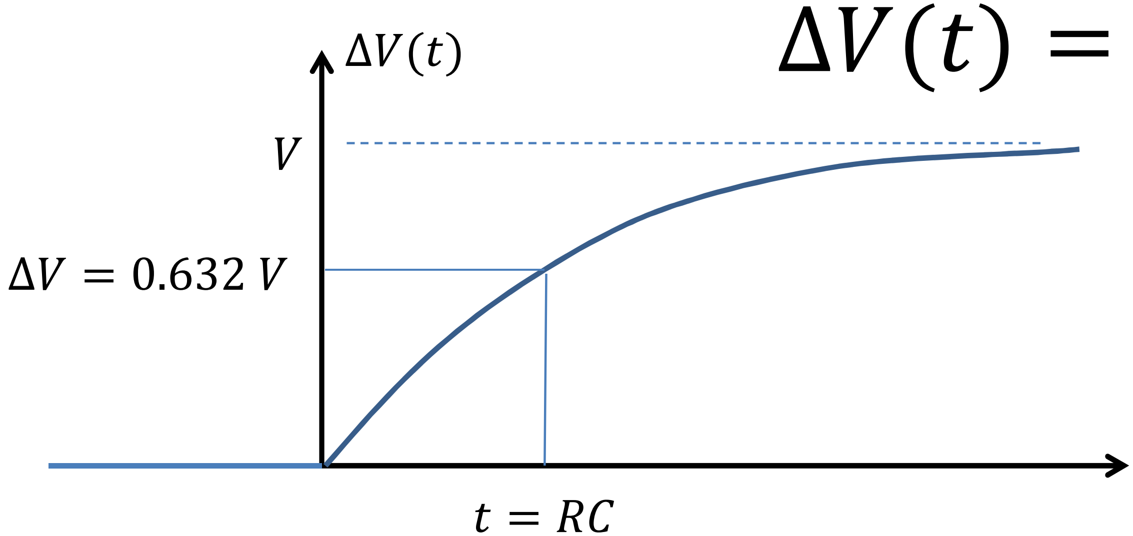
$$V - I(t)R - \Delta V = 0$$

$$\Delta V(t) = V - I(t)R = V\left(1 - e^{-t/RC}\right)$$

Charging a Capacitor



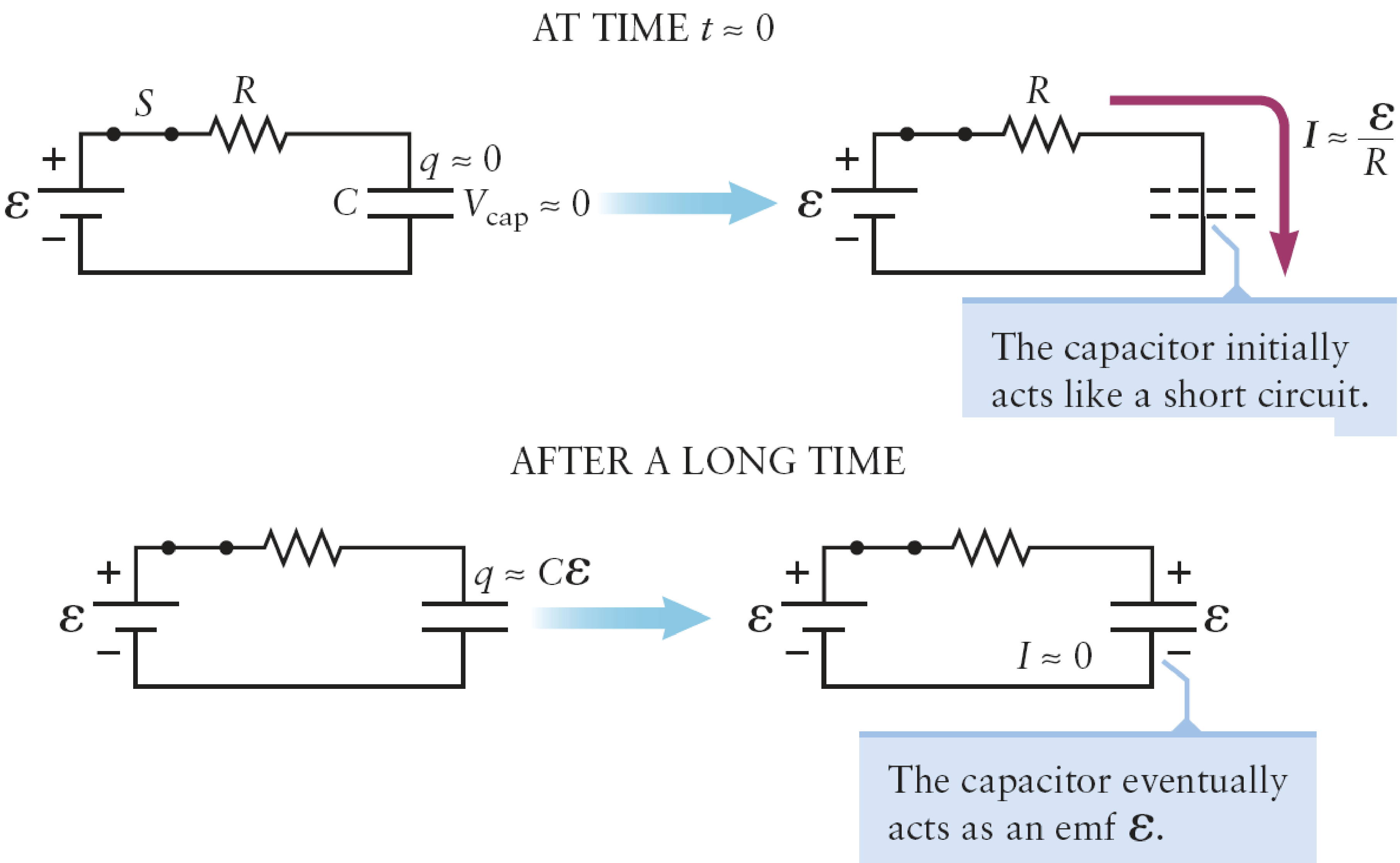
$$\Delta V(t) = V\left(1 - e^{-t/RC}\right)$$



The capacitor *initially* acts like a **short circuit** (zero resistance) but *eventually* acts like an **open circuit** (infinite resistance).

Charging a Capacitor

DEMO



Time Constant

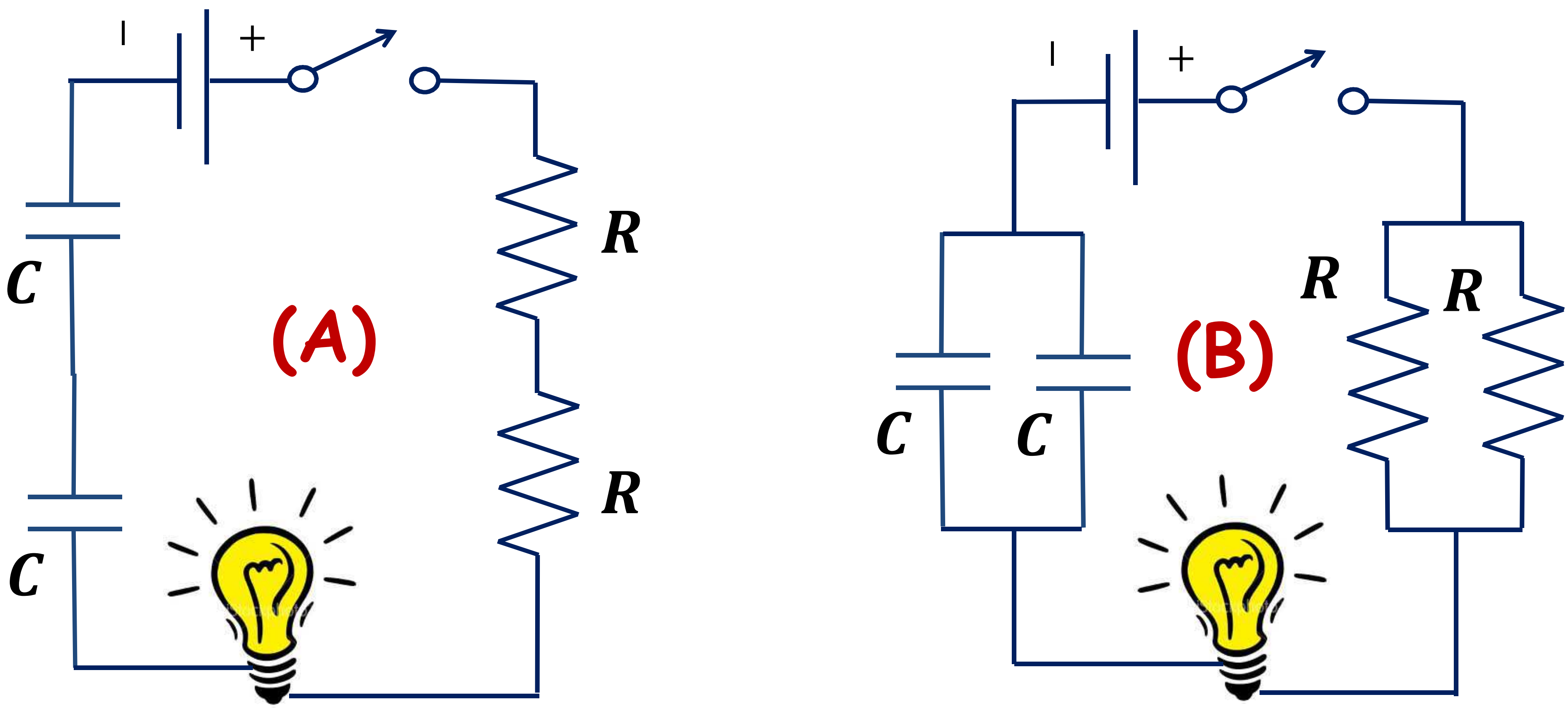
- The quantity $\tau = RC$ is called the ***time constant***.
- Units:

$$[R] \cdot [C] = \left[\frac{\mathrm{V}}{\mathrm{A}}\right] \cdot \left[\frac{\mathrm{C}}{\mathrm{V}}\right] = \left[\frac{\mathrm{C}}{\mathrm{C/s}}\right] = \mathrm{s}$$

- It is the characteristic time needed to charge or discharge the circuit.
- Larger τ means it charges or discharges more slowly.

Question

- In which circuit will the light stay lit the longest when the switch is closed at $t = 0$?

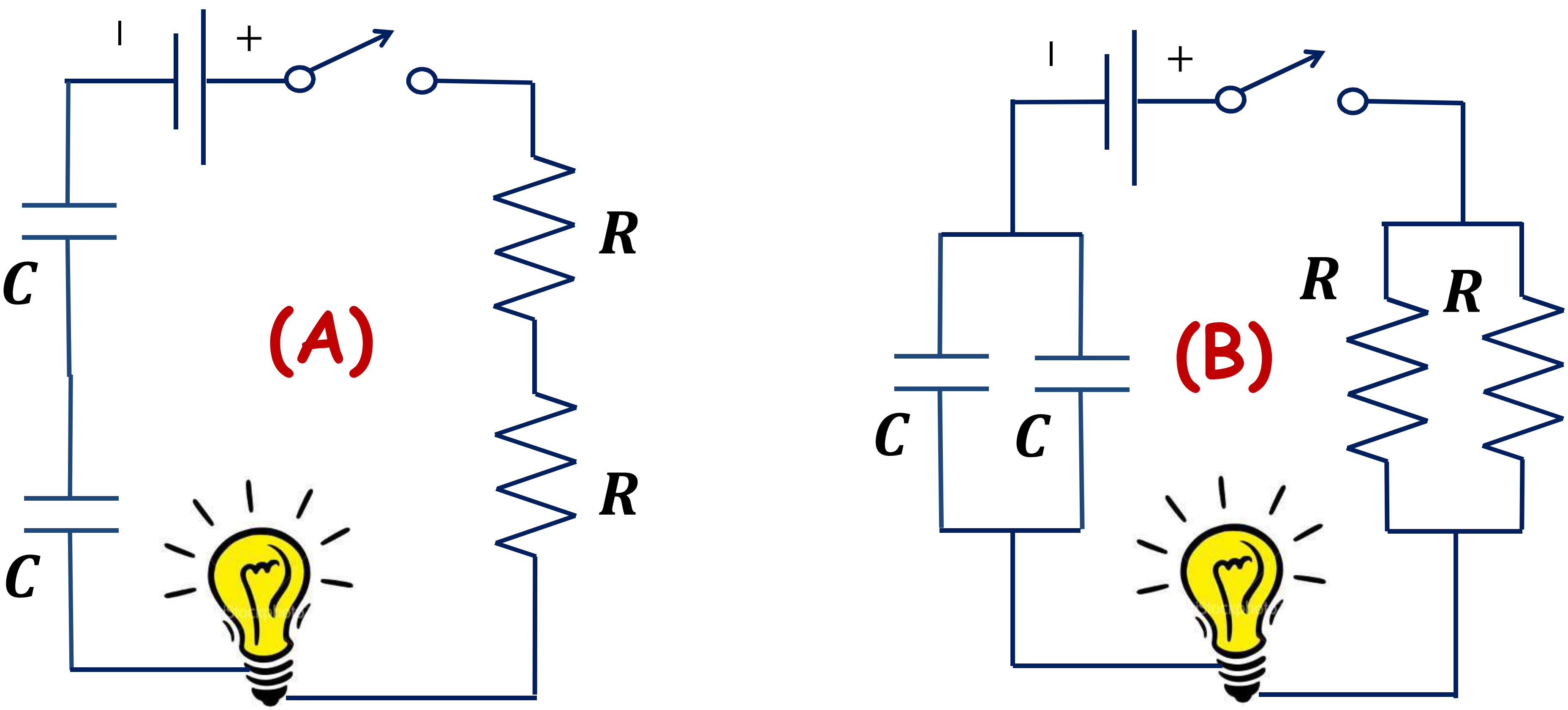


Question

(a) A will stay lit longer than B

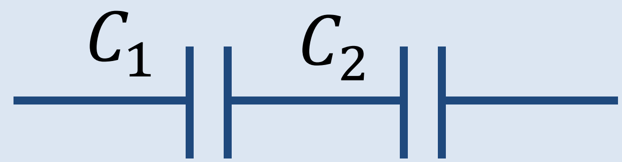
(b) B will stay lit longer than A

(c) They will both be the same

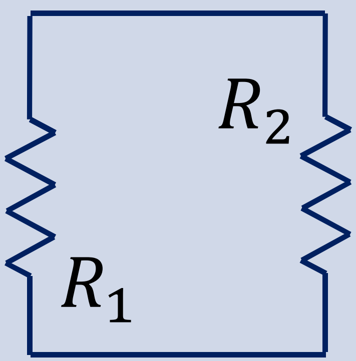


Series and Parallel

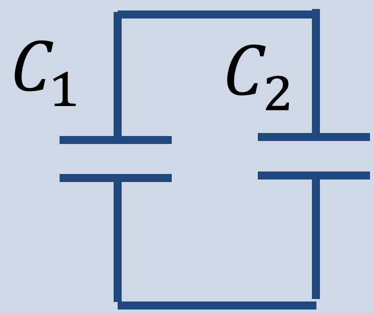
$$R = R_1 + R_2$$



$$C = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$



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

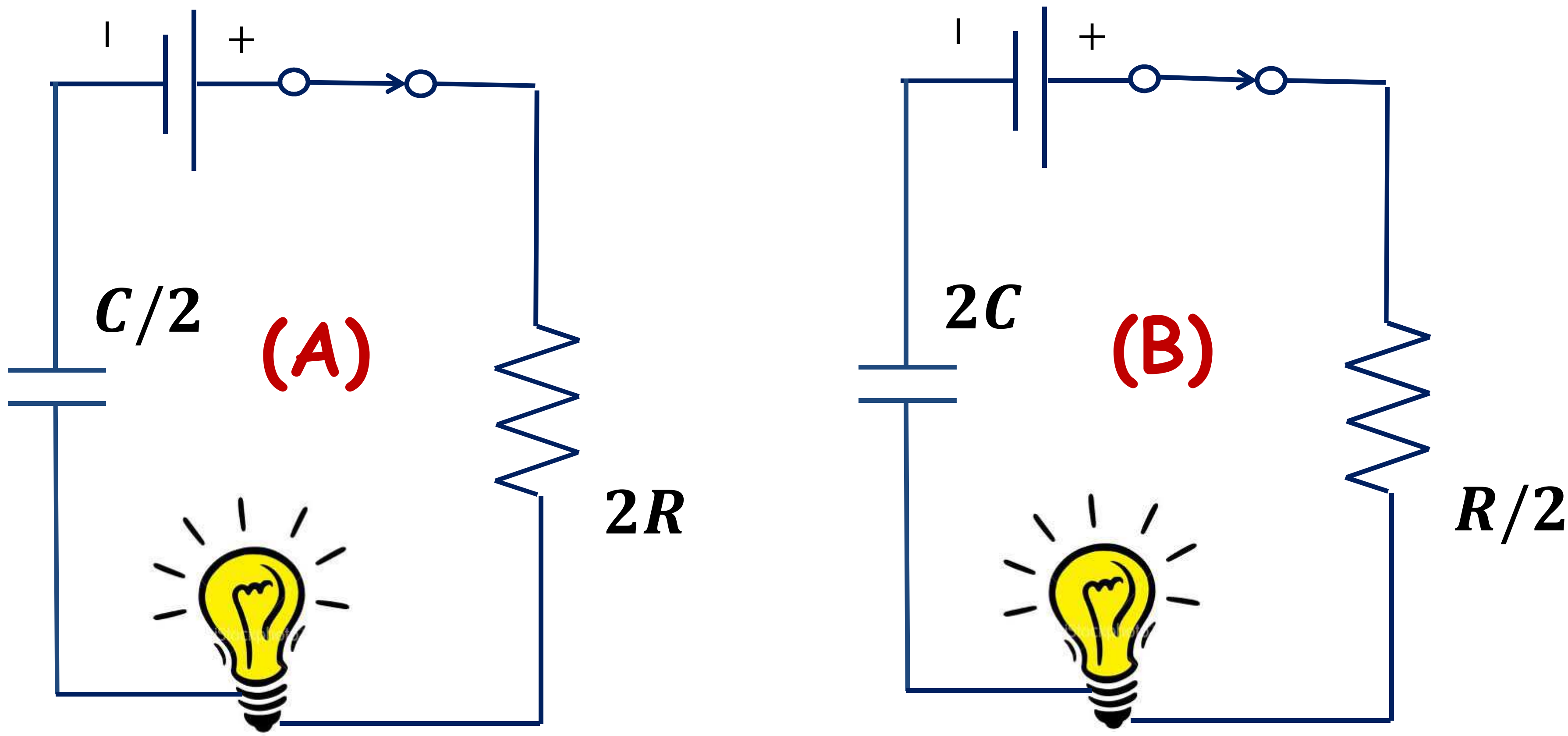


$$C = C_1 + C_2$$

Question

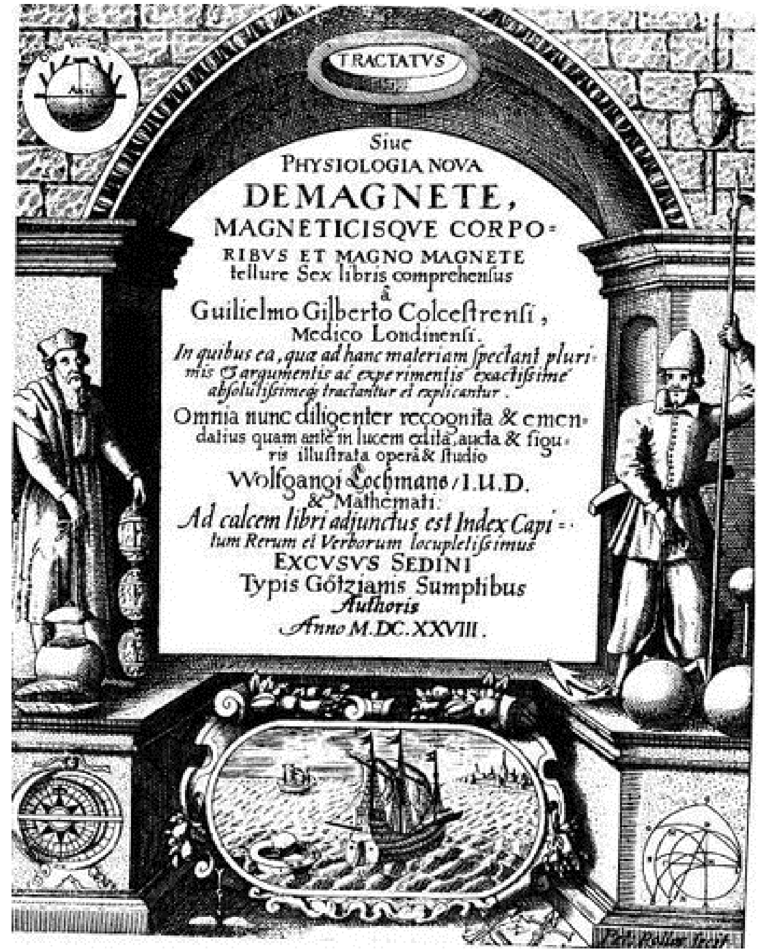
Time constants are equal:

$$\tau = (2R)\left(\frac{C}{2}\right) = \left(\frac{R}{2}\right)(2C) = RC$$



Magnetism

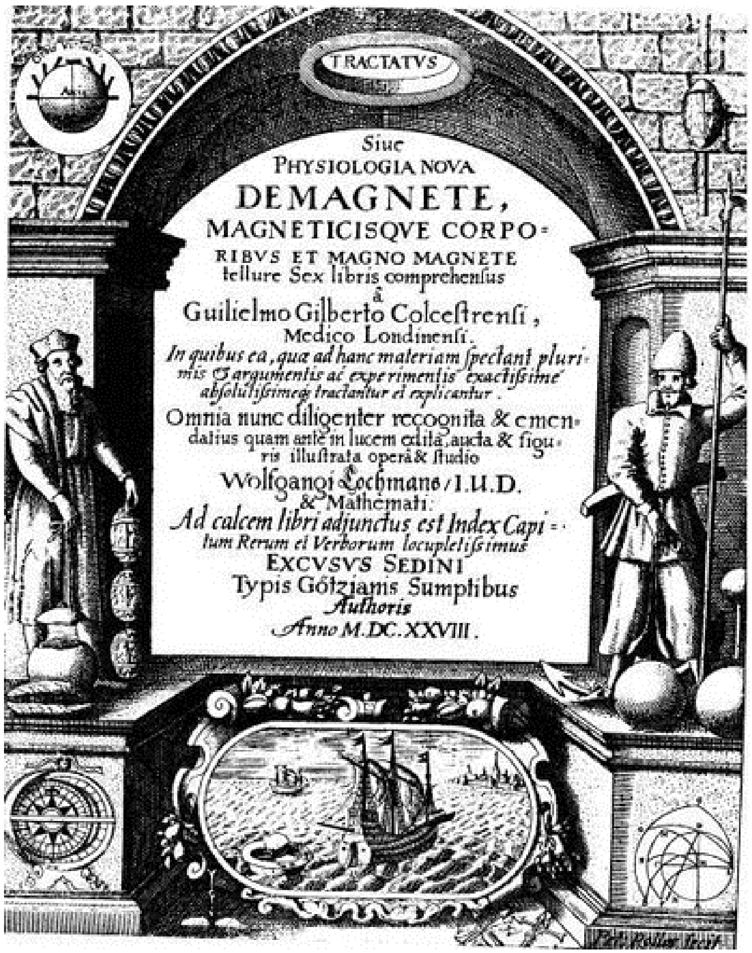
Shen Kuo (1031-1091)



William Gilbert (1600)

Clicker Question

Which publication would you want to read?



TRACTATVS

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PHYSIOLOGIA NOVA

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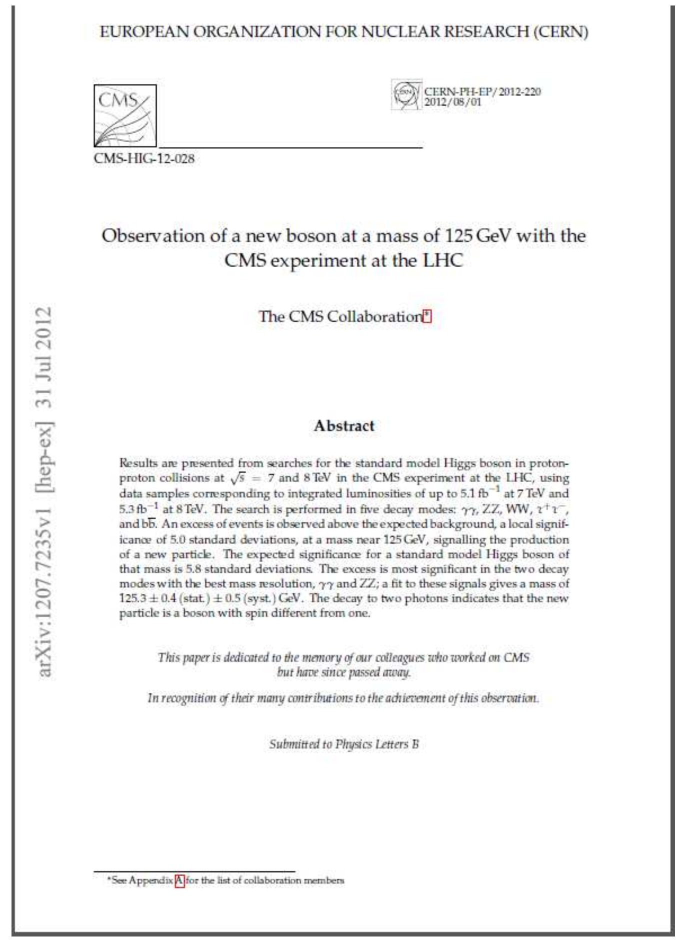
(a)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CMS-HIG-12-028

CERN-PH-EP/2012-220
2012/08/01

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

The CMS Collaboration*

arXiv:1207.7235v1 [hep-ex] 31 Jul 2012

Abstract

Results are presented from searches for the standard model Higgs boson in proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV in the CMS experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, WW, $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of 125.3 ± 0.4 (stat.) ± 0.5 (syst.) GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away.

In recognition of their many contributions to the achievement of this observation.

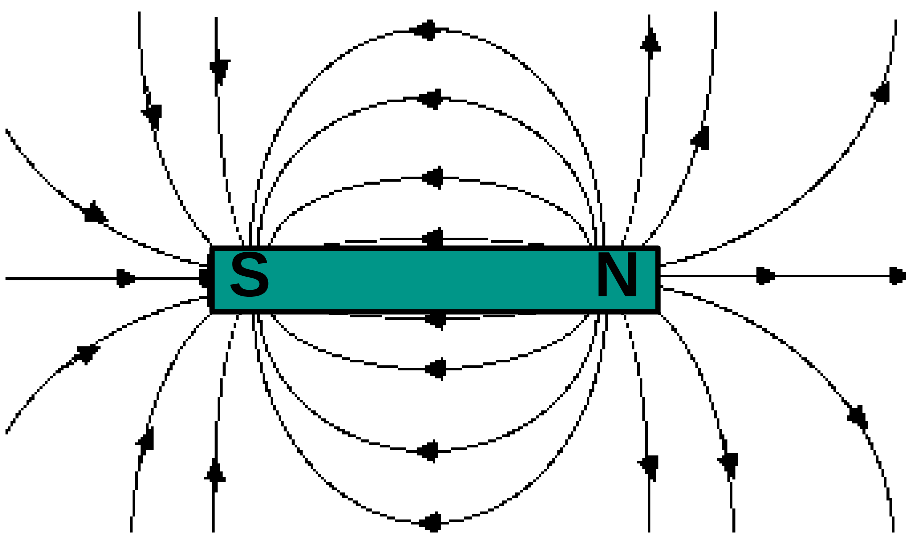
Submitted to Physics Letters B

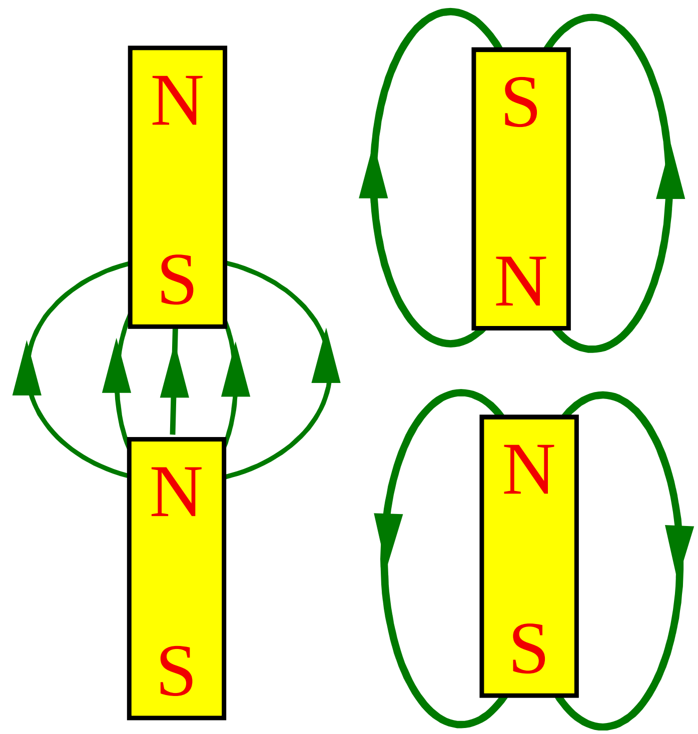
*See Appendix A for the list of collaboration members

(b)

Magnetism

- Bar magnets always two opposite poles
  - Like poles repel, unlike poles attract
  - We can describe the magnetic field the same way we talked about electric fields.





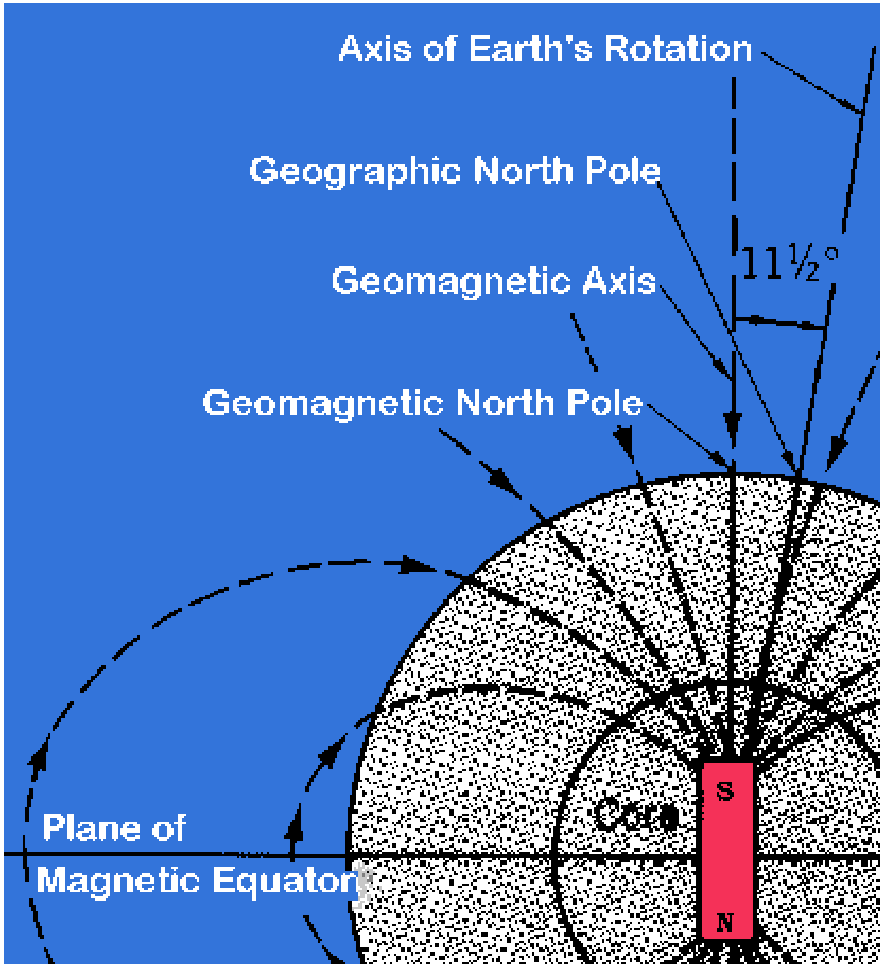
Magnetic Monopoles

- Can you cut the end off a magnet to get just the North or South poles?

- Most elementary particles behave like little bar magnets: they have a north end and a south end.
  - Although they are point-like we can still talk about which way their magnetic field is pointing
- In principle, a fundamental particle with a magnetic charge ***could*** exist, but we haven't found any evidence that they do.

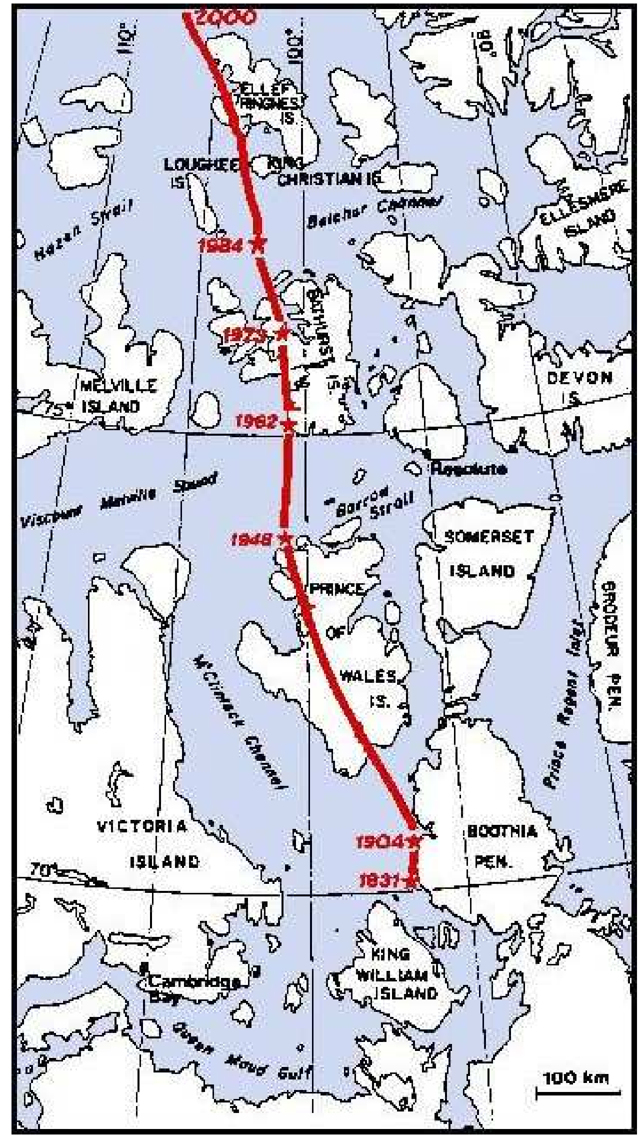
Earth's Magnetic Field

- By convention, the N end of a bar magnet is what points at the Earth's North Geographic Pole.
- Since opposite poles attract (analogous to opposite electric charges), the "North Geomagnetic Pole" is in fact a magnetic SOUTH pole, by convention.
- Confusing, but it's just a convention. Just remember that we define N for bar magnets as pointing to geographic North.

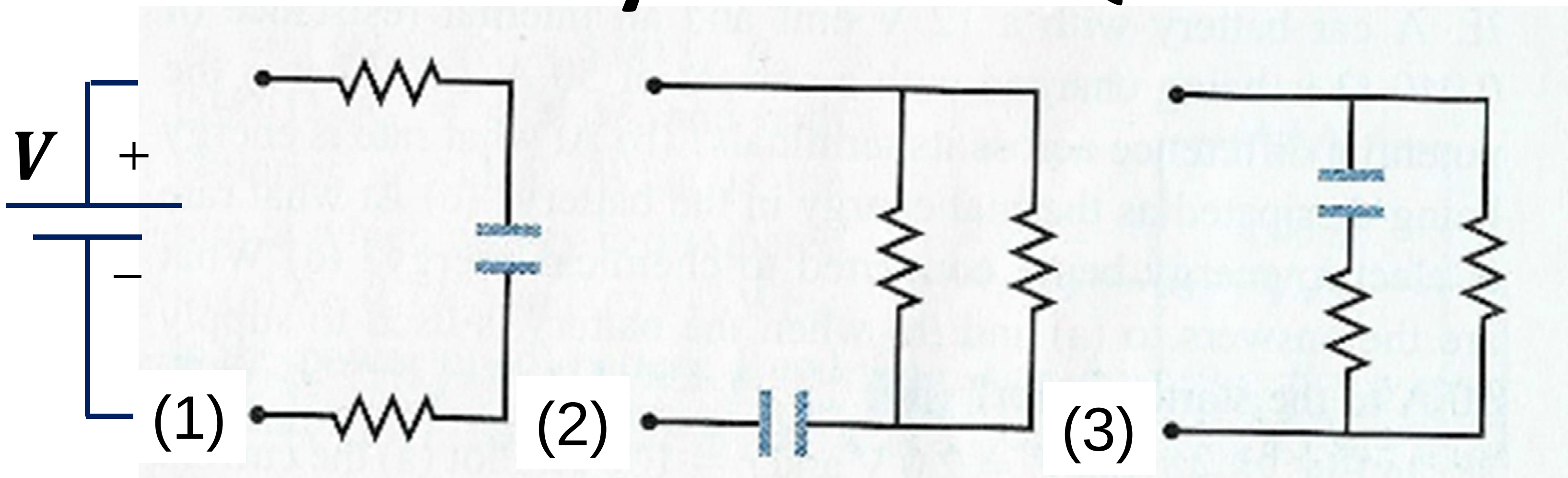


Earth’s Magnetic Field

- The orientation of the earth’s magnetic dipole is not constant:
  - From 1904 to 1984 it moved 750 km (9.4 km/year)
- The rate of change is also not constant:
  - From 1973 to 1984 it moved 120 km (11.6 km/year)



Thursday's Clicker Question



The figure shows three section of circuit that are to be connected in turn to the same battery via a switch. The resistors are identical, as are the capacitors. Rank the sections according to the final charge ($t \rightarrow \infty$) on the capacitor.

(a) 2 = 3 > 1

(b) 1 = 2 = 3

(c) 3 > 1 > 2

(d) 1 > 3> 2

(e) 2 > 3 > 1