Lecture 5: More About Circuit Devices

- Resistors
- Power limitations of physical resistors
- Capacitors and the energy they store
- Batteries and their energy rating
- Transistors and their impact

Resistors are devices that obey Ohm's Law

- Resistors always dissipate power; they heat up
- Resistors do not store or deliver (DC) energy
- Using Ohm's Law…

$$P = I\,V = \frac{V^2}{R} = I^2 R$$

In History…

Henry **Cavendish** conducted similar experiments over 40 years earlier than Georg **Ohm** using Leyden jars for voltage sources and the shock felt by his body as an *ad hoc* ammeter!

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Resistors $I = \frac{V}{R}$

$$P = I\,V = \frac{V^2}{R} = I^2 R$$

Q: What power is dissipated by a $100\ \Omega$ resistor when a 6 V drop is measured across it?

A. $\boxed{360\ mW}$
B. $160\ W$
C. $360\ kW$
D. $160\ MW$
E. $360\ GW$

Q: A 100 Ω resistor is rated at 0.25 W. What is its maximum rated current?

A. $\boxed{50\ mA}$
B. $400\ mA$
C. $50\ A$
D. $400\ A$
E. $50\ kA$

Capacitors: store electrical energy

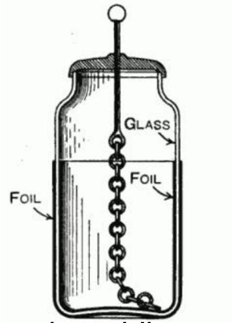
$$C = \frac{Q}{V}$$

C, the capacitance, is the charge-to-voltage ratio of a capacitor

$$E_{capacitor} = \frac{1}{2}CV^2$$

In History…

The first device for storing electrical energy became known as Leyden Jar after the city in which it was built (1745). It had a capacitance of about $1\ nF$.



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In History…

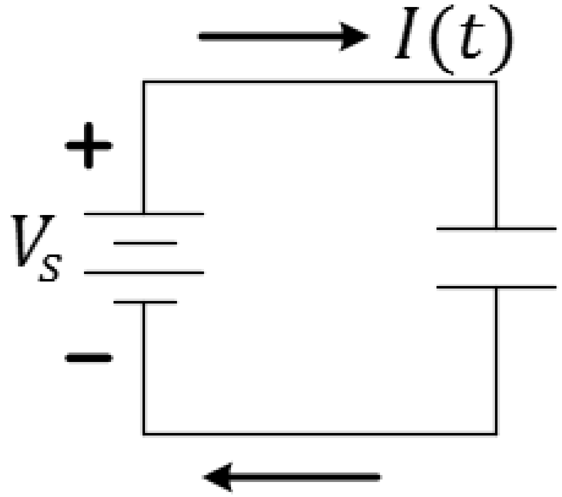
Yes, **Benjamin Franklin** collected electrostatic charge from a storm using a kite in 1752, but also formulated the *principle of conservation of electric charge* and coined the terms "positive" and "negative" with respect to the charge carriers (current).

Capacitors

Q: At what voltage would a $1\ nF$ capacitor have the energy to lift $100\ kg$ (a camel, perhaps?) by $2\ cm$?

A. $200\ mV$
B. $250\ mV$
C. $200\ V$
D. $250\ V$
E. $\boxed{200\ kV}$

Efficiency of Charging a Capacitor



- $\Delta E_{battery} = \Delta E_{capacitor} + \Delta E_{waste}$
- $\Delta E_{waste} \geq \frac{1}{2} C V^2$
- $\Delta E_{battery} \approx \frac{1}{2} C V^2 + \frac{1}{2} C V^2 = C V^2$

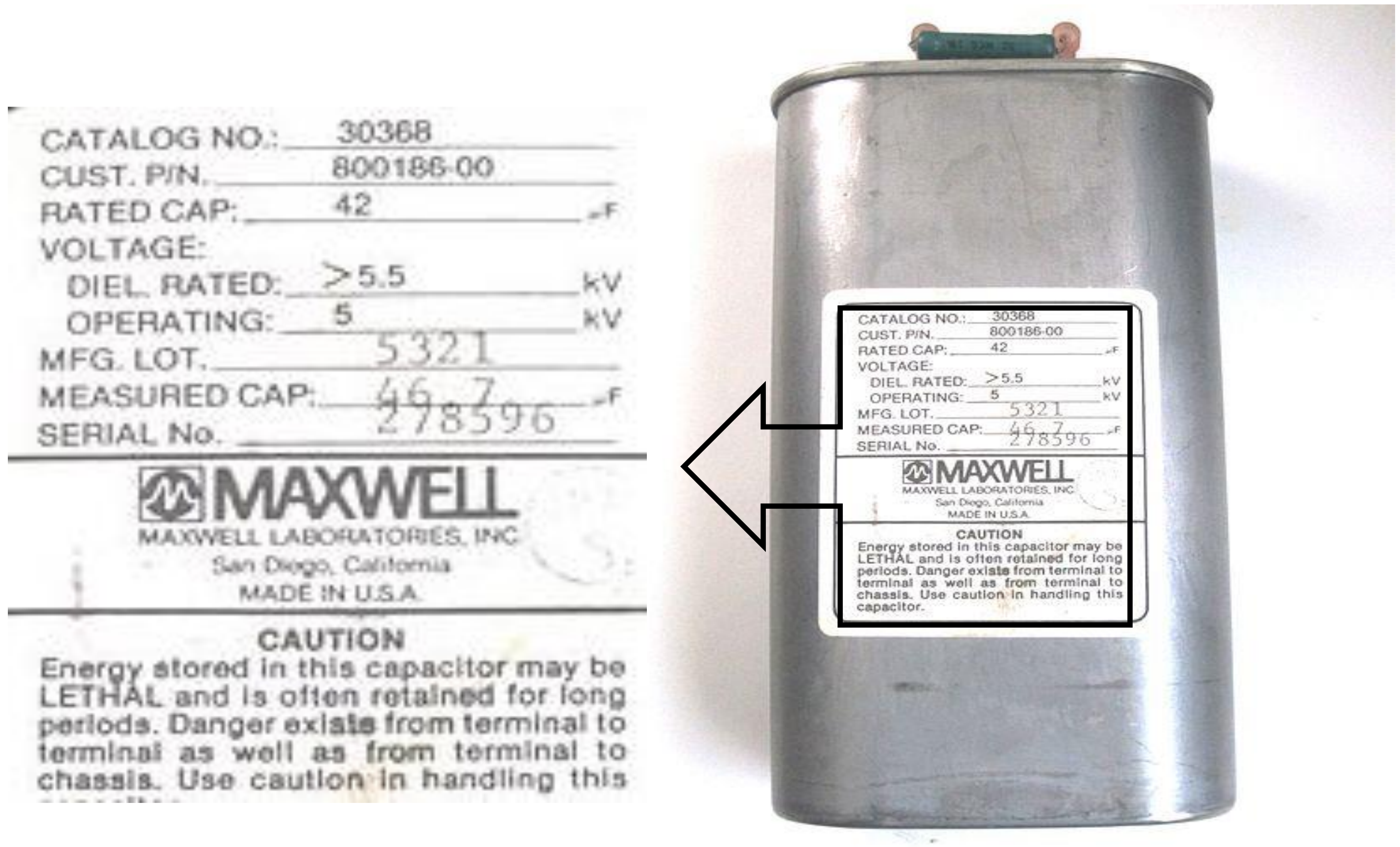
Physics 212

Special Capacitor: Defibrillator

Q: How much energy, E_{cap}, is in the 42 µF defibrillator capacitor charged to 5 kV?

$E_{cap} =$

A. $5.25\ mJ$
B. $5.25\ J$
C. $\boxed{525\ J}$
D. $525\ MJ$
E. $525\ GJ$



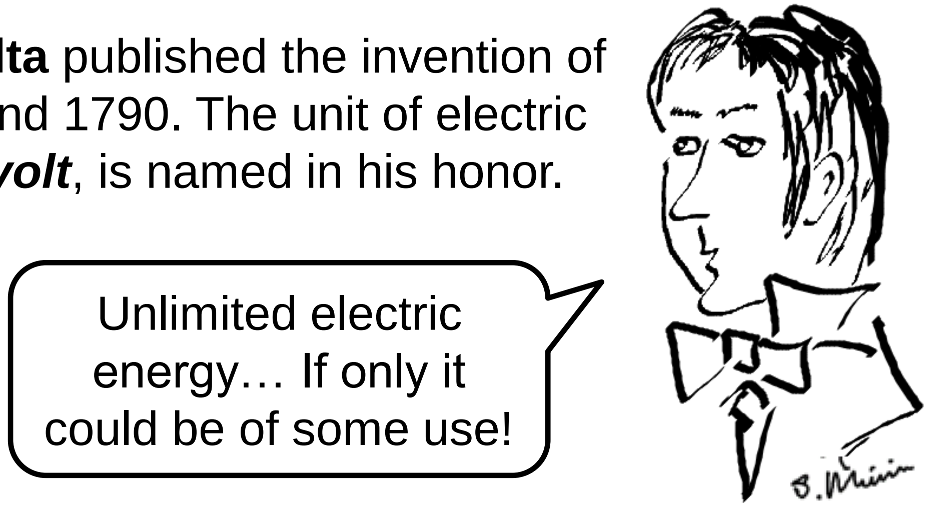
Q: Half of the capacitor's charge, Q, is then drained off. How much energy does it hold now?

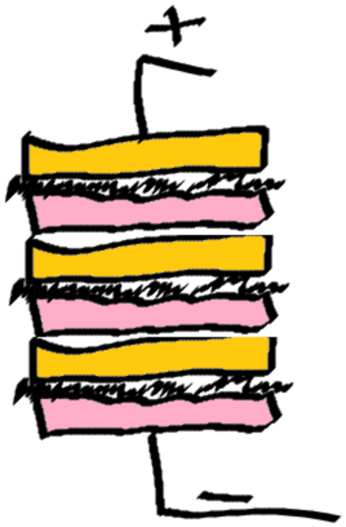
A. $\frac{E_{cap}}{8}$
B. $\frac{E_{cap}}{4}$
C. $\boxed{\frac{E_{cap}}{2}}$
D. E_{cap}
E. $2E_{cap}$

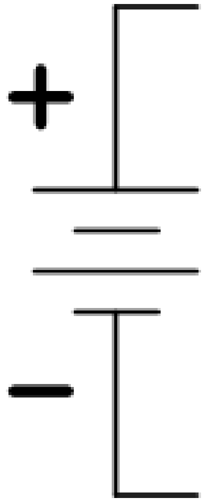
Batteries store and generate electrical energy with a chemical reaction

In History…

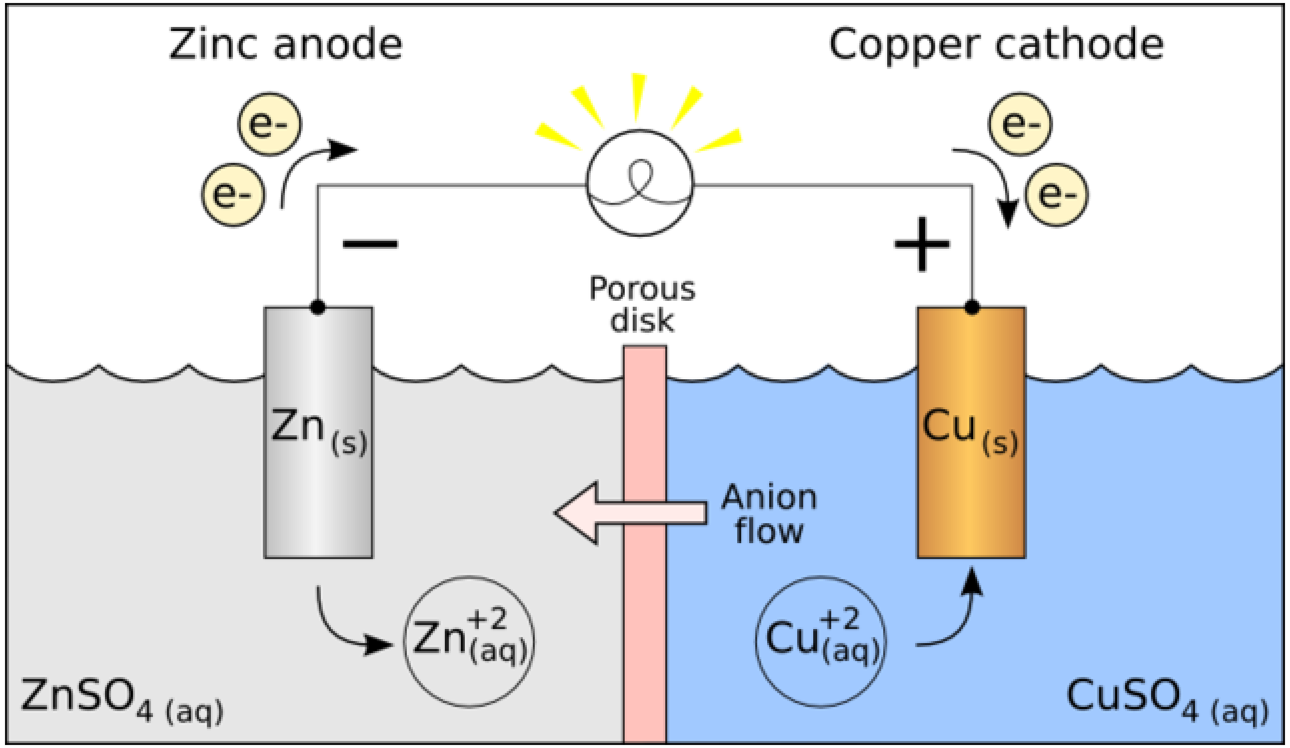
Alessandro Volta published the invention of the battery around 1790. The unit of electric "pressure", the ***volt***, is named in his honor.







Explore More! on Batteries



Read more:
https://en.wikipedia.org/wiki/Galvanic_cell

Chemistry 102 and 103!

Batteries

Q: How much charge moves through a 9-V battery to provide 3 J of energy?

A. $\boxed{0.33\ C}$
B. $3\ C$
C. $27\ C$
D. $330\ MJ$
E. $27\ kC$

Q: If a battery is labeled at 9 V and 500 mAh, how much energy does it store in joules?

1mAh=0.001A×3600s=3.6As = 3.6 Coulomb

A. $18\ mJ$
B. $56\ mJ$
C. $4.5\ J$
D. $18\ J$
E. $\boxed{16\ kJ}$

Q: For how long can such battery power an LED if that draws 50 mA of current?

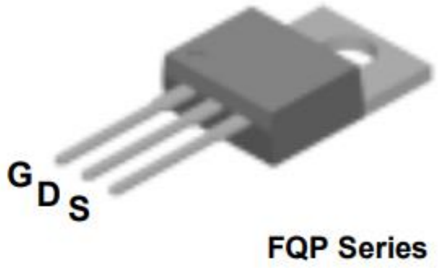
A. $0.1\ hr$
B. $1\ hr$
C. $5\ hr$
D. $\boxed{10\ hr}$
E. $50\ hr$

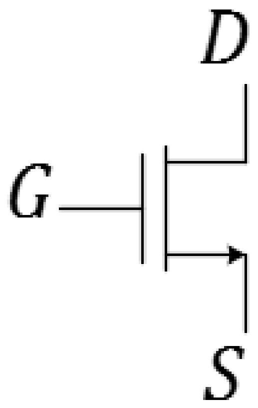
The Transistor

- The transistor changed the world!
- Prior to the transistor, we had the vacuum tube:
  - Large
  - Hot
  - Low efficiency
  - High failure rate
  - Could not be integrated into an IC

Example: MOSFET:

Physical Circuit schematic





L5 Learning Objectives

a. Compute current/voltage rating for a resistor based on its power rating
b. For a capacitor, compute stored energy, voltage, charge, and capacitance given any of the two quantities.
c. Compute energy stored in a battery and discharge time.
d. Identify features of the transistor that changed everything!