PHYSICS 2DL – SPRING 2010

MODERN PHYSICS LABORATORY

Monday April 12, 2010

Prof. Brian Keating

UCSD

UCSD

2Day in 2DL

- Review Errors from Chi-squared fits
- Theory of experiment 3.
- Theory of experiment 4-6 in lab this week.
- You will choose your lab schedule and lab partner this week in lab if you haven't yet.
- You start doing the labs next week
- HW #1 due next week in lab.

Error Propagation HW Example

- Using a stopwatch, with uncertainty of 0.1 sec, measure period to better than the resolution of the stopwatch.
- E.g., one period takes ~0.5±0.1 sec,
- 5 periods takes 2.4±0.1 sec, how long is each period?
- =0.48±0.02 sec
- 20 periods takes 9.4±0.1 sec, how long is each period?
- 0.470±0.005 sec

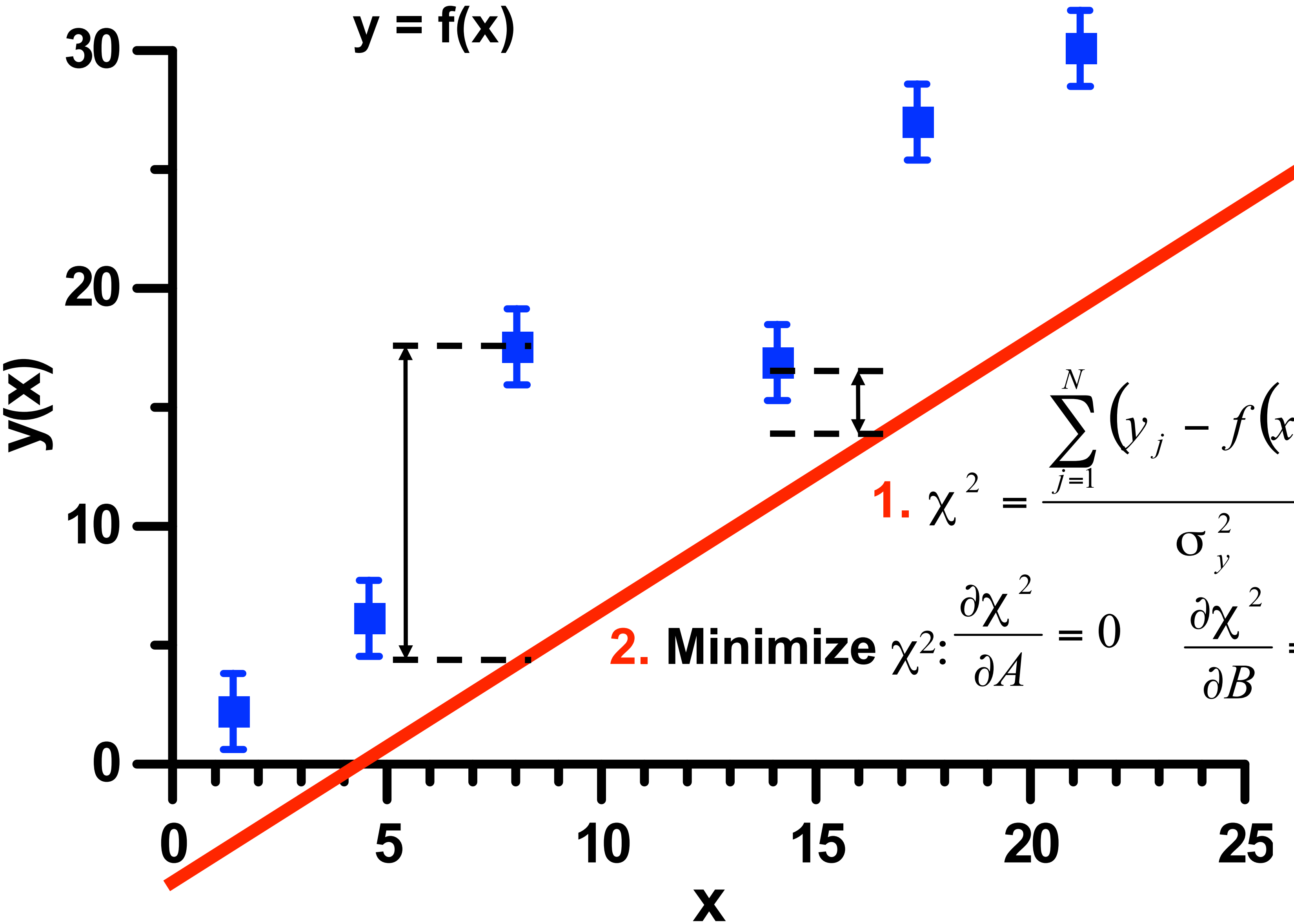
Error propagation

$$\delta q = \left|\frac{dq}{dx}\right| \delta x$$

$$q = q(x, y, z)$$

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x}\delta x\right)^2 + \left(\frac{\partial q}{\partial y}\delta y\right)^2 + \ldots + \left(\frac{\partial q}{\partial z}\delta z\right)^2}$$

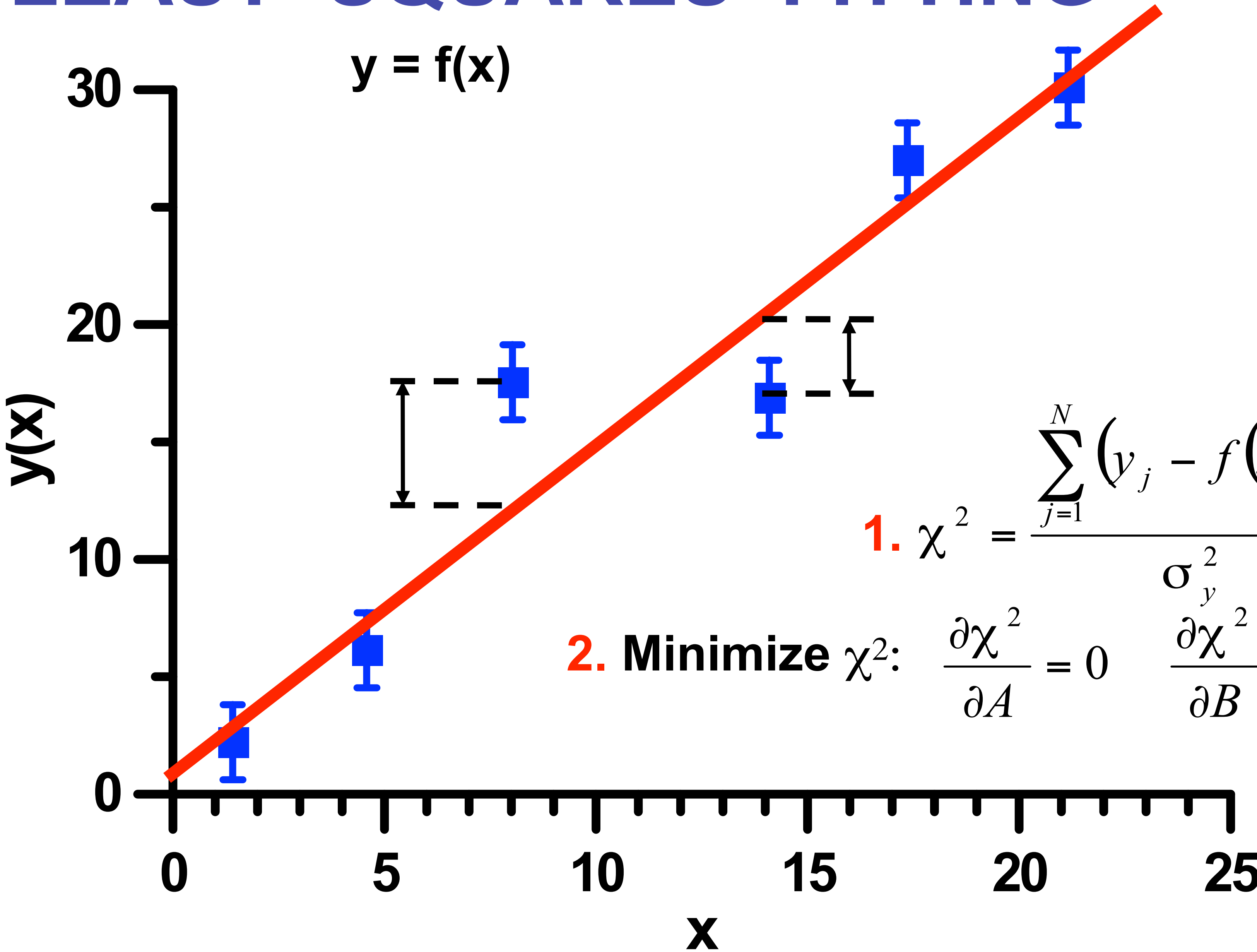
LEAST SQUARES FITTING



1. $$\chi^2 = \frac{\sum_{j=1}^{N} \left(y_j - f(x_j)\right)^2}{\sigma_y^2}$$

2. **Minimize** χ^2: $$\frac{\partial \chi^2}{\partial A} = 0 \qquad \frac{\partial \chi^2}{\partial B} = 0$$

LEAST SQUARES FITTING



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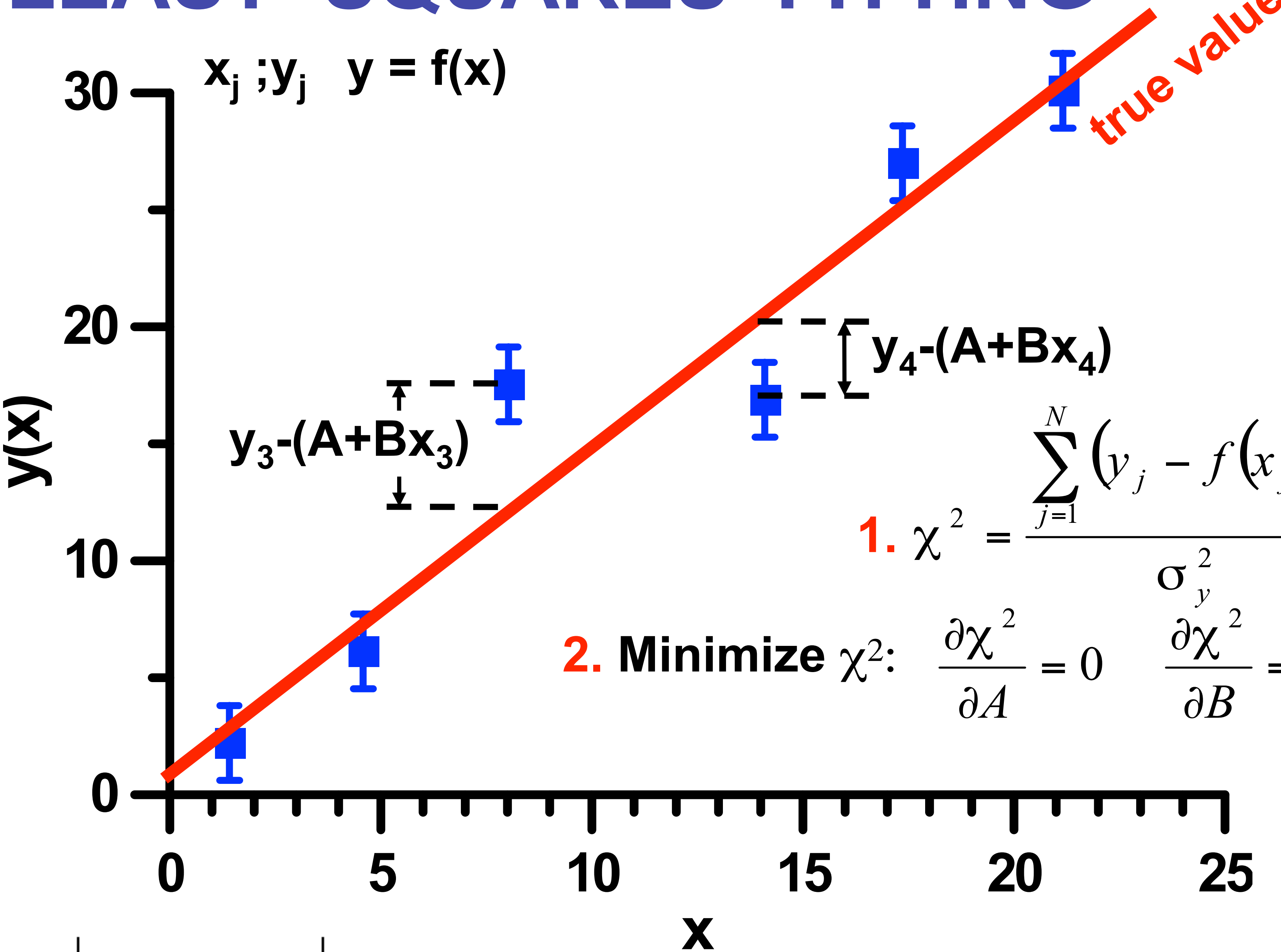
LEAST SQUARES FITTING



1. $$\chi^2 = \frac{\sum_{j=1}^{N} \left(y_j - f(x_j)\right)^2}{\sigma_y^2}$$

2. Minimize χ^2: $\frac{\partial \chi^2}{\partial A} = 0 \quad \frac{\partial \chi^2}{\partial B} = 0 \quad \cdots$

$$t = \frac{\left| x_{measured} - x_{expected} \right|}{\sigma_{total}}$$

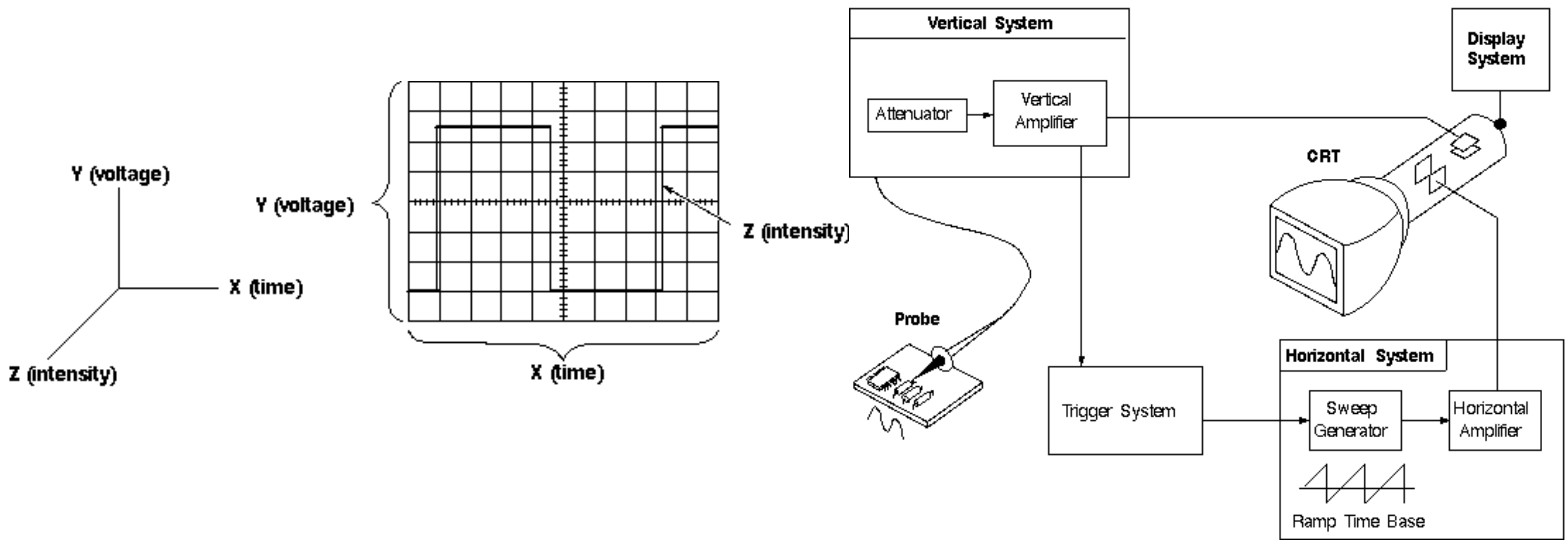
3. → A in terms of x_j y_j ; B in terms of x_j y_j , …

Electronics Recap for Lab 3

- You should play around with lab equipment this week.

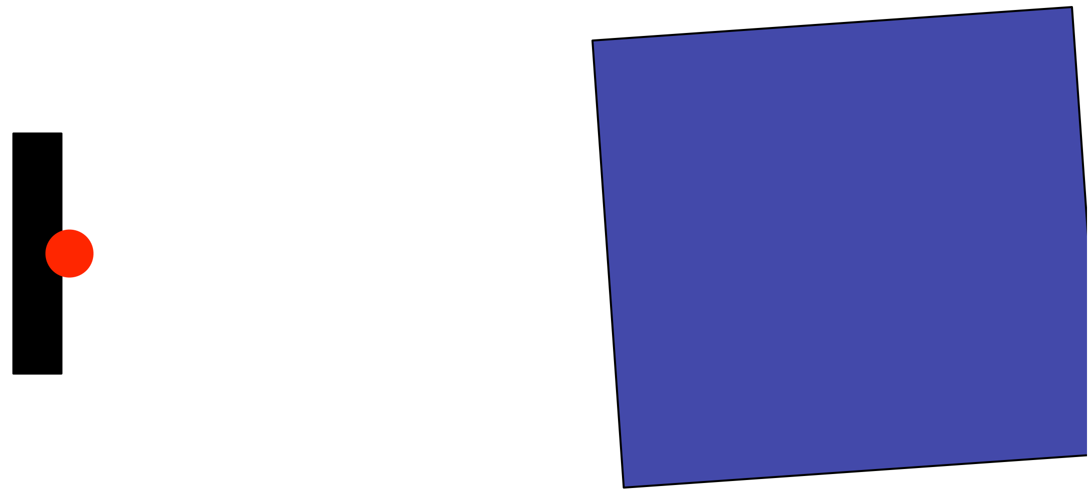
Oscilloscopes

•You can determine the time and voltage values of a signal.
•You can calculate the frequency of an oscillating signal.
•You can tell if a malfunctioning component is distorting the signal.
•You can find out how much of a signal is direct current (DC) or alternating current (AC).
•You can tell how much of the signal is noise and whether the noise is changing with time.



Oscilloscope

J.J.Thomson
N.P. physics 1906



Oscilloscope

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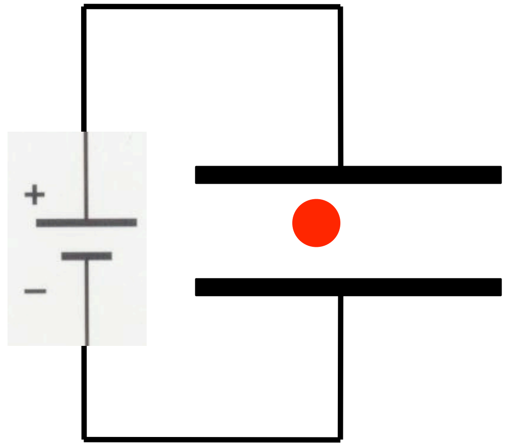

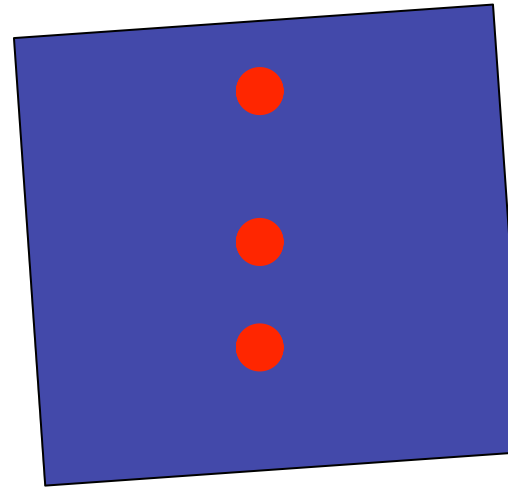

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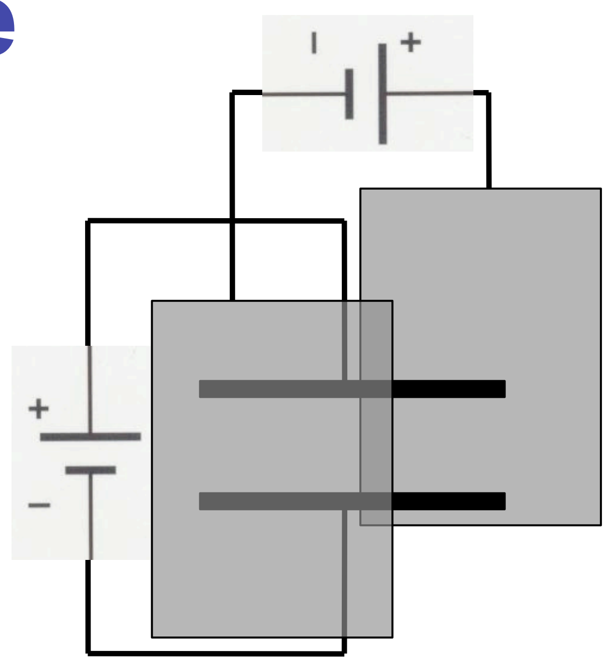
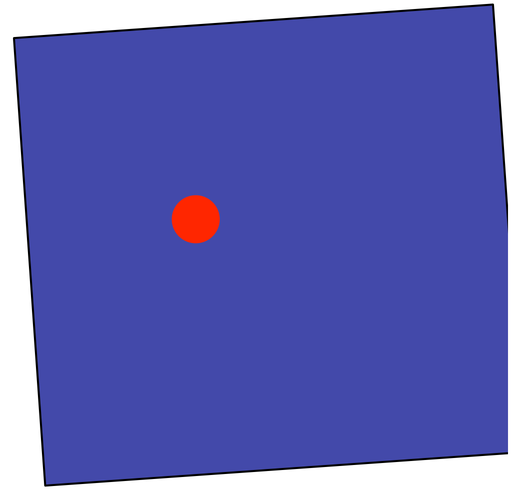
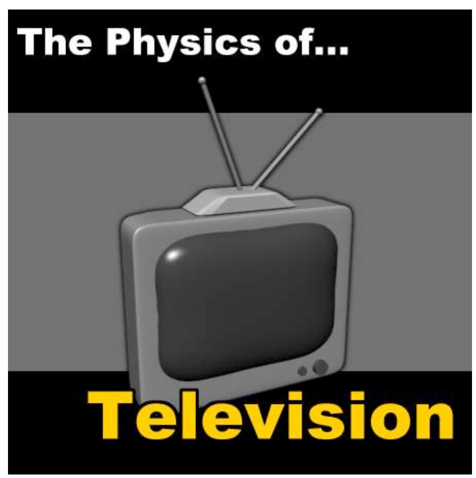
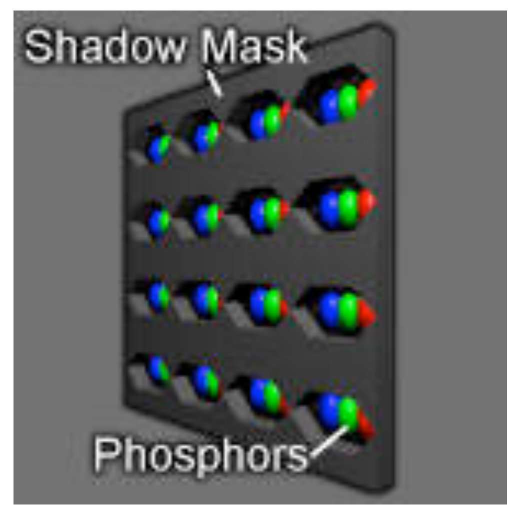


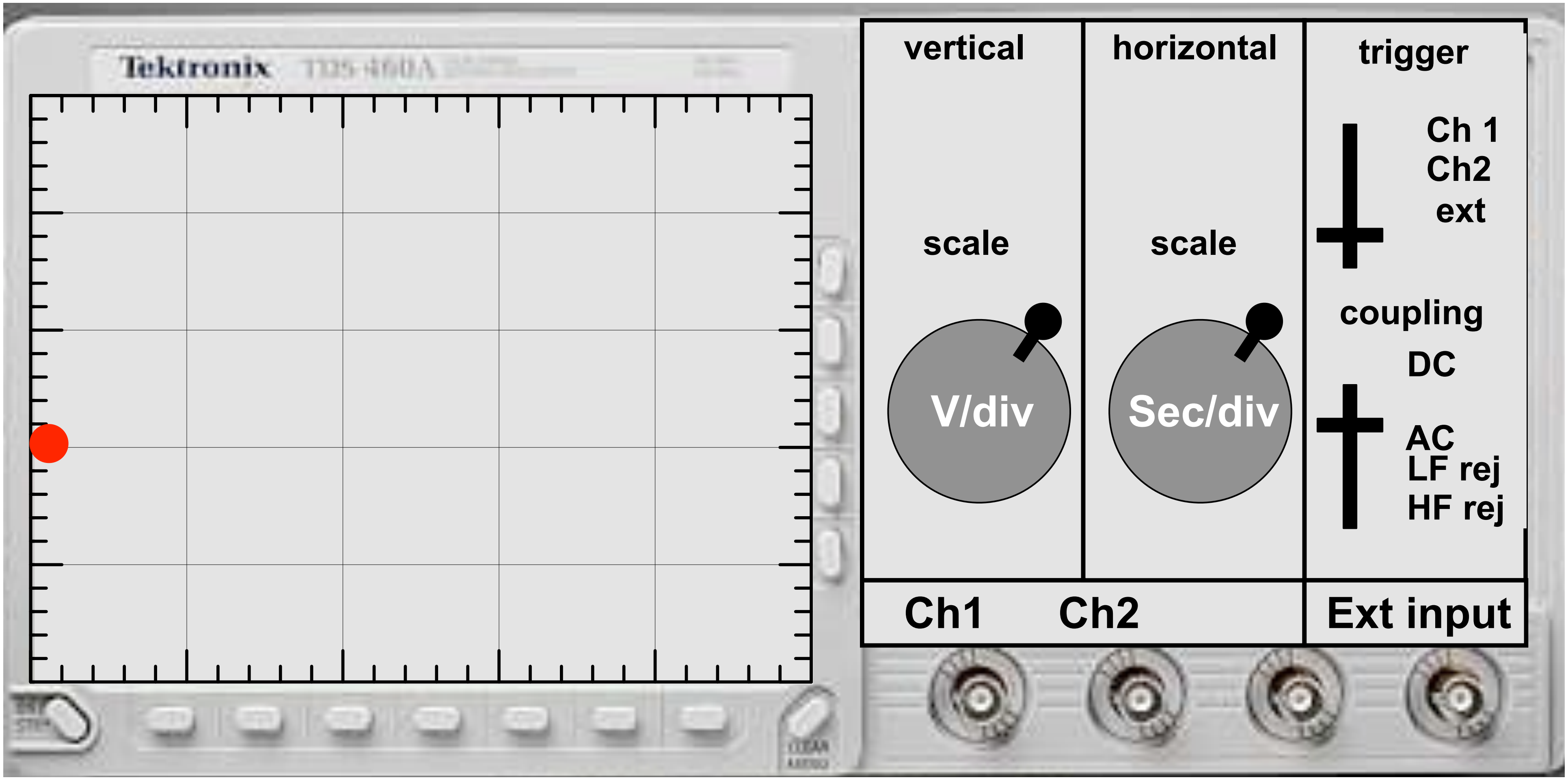


Similar to the TV…

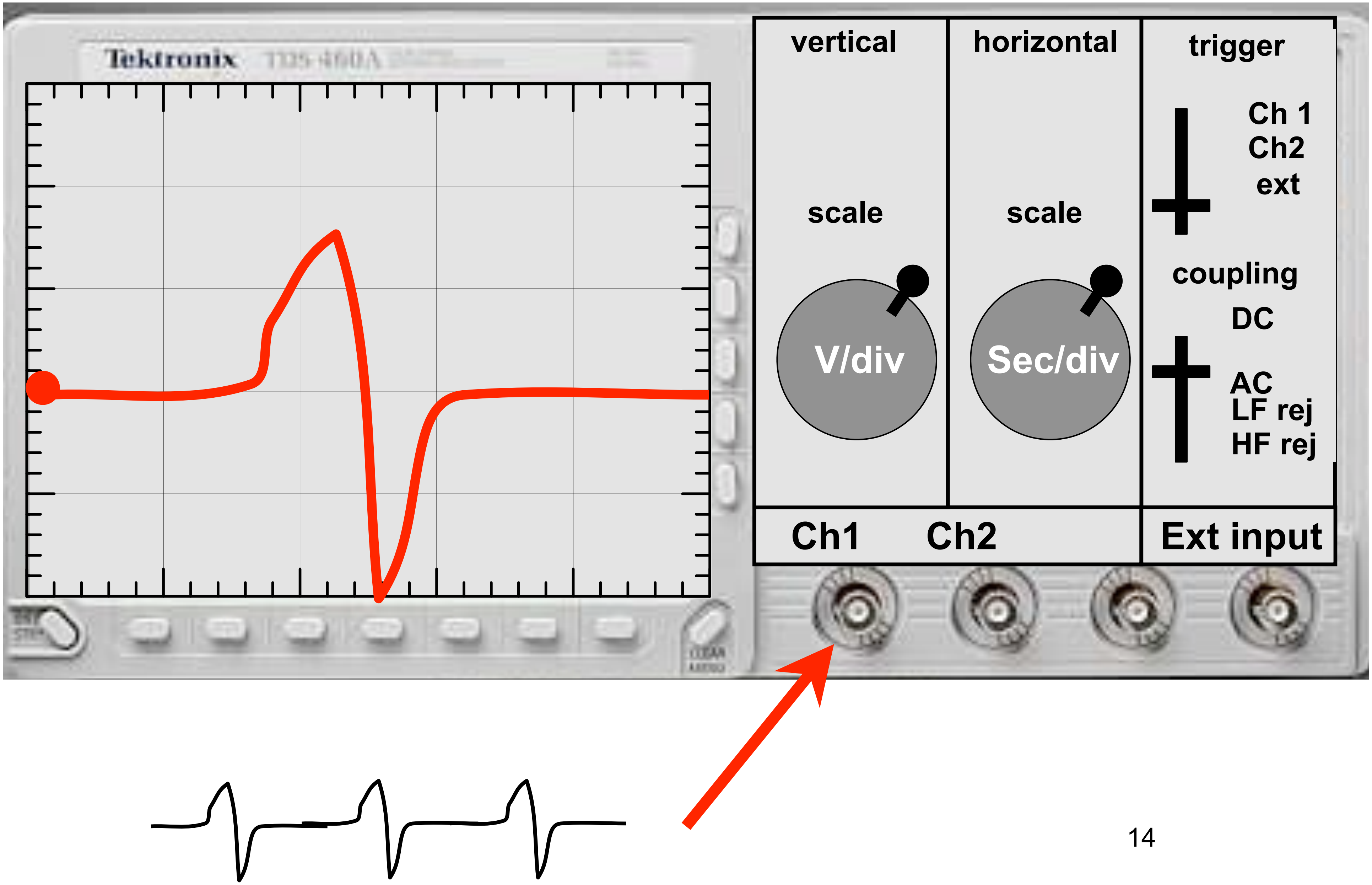




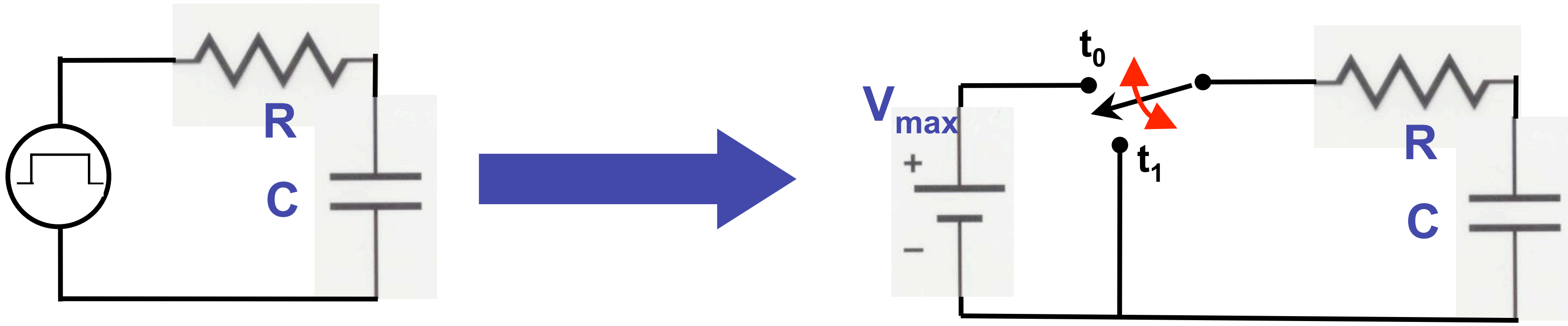
Oscilloscope

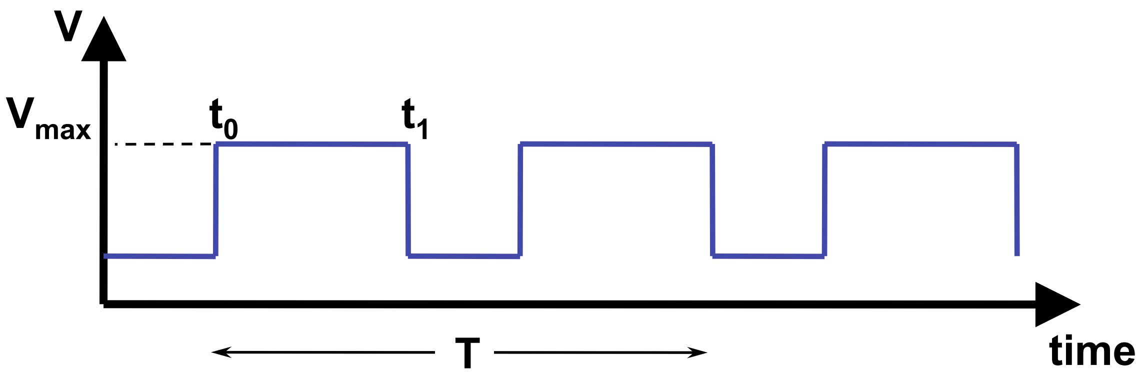


Oscilloscope



RC circuit

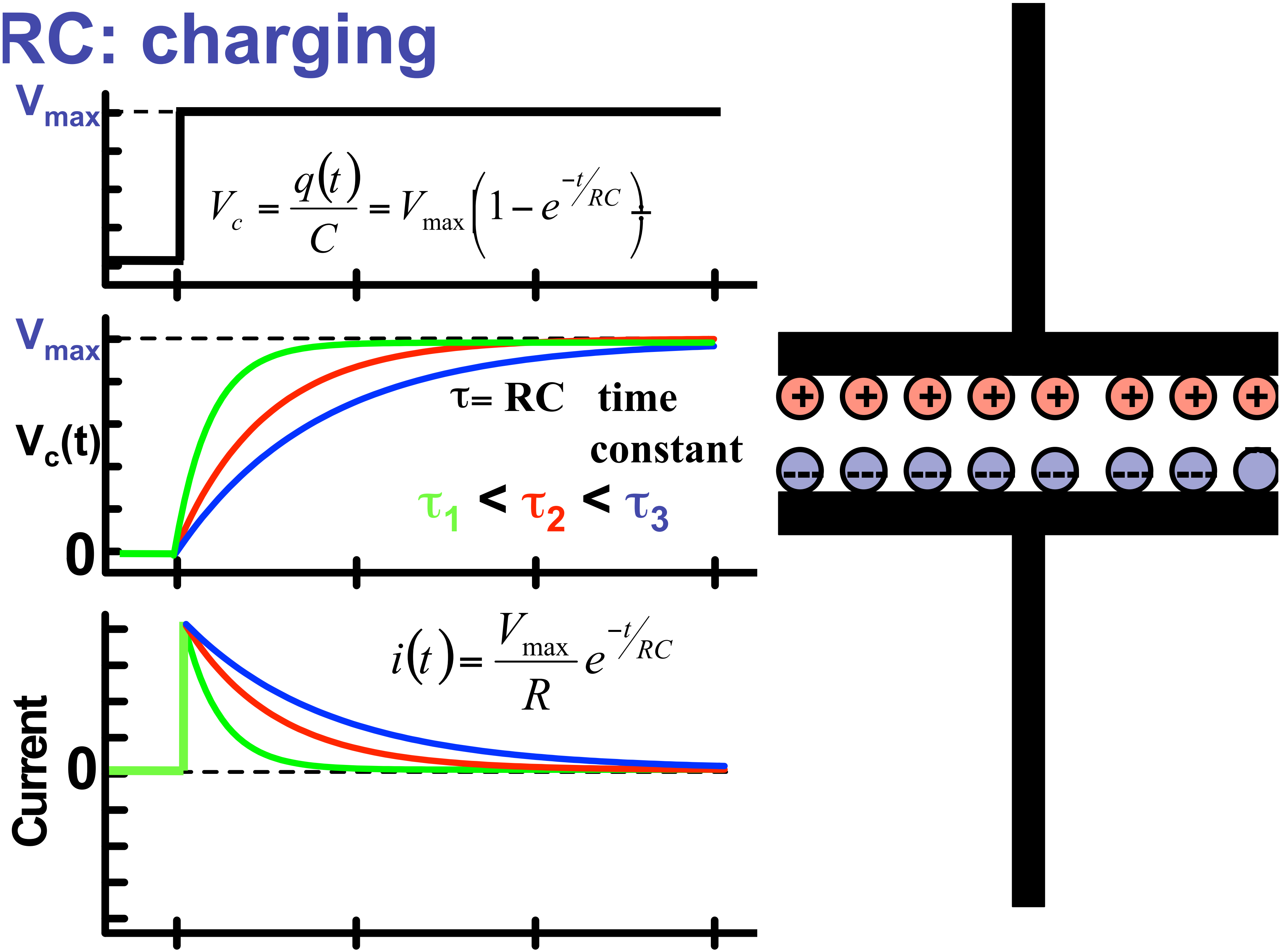




$$\sum_k i_k = 0$$

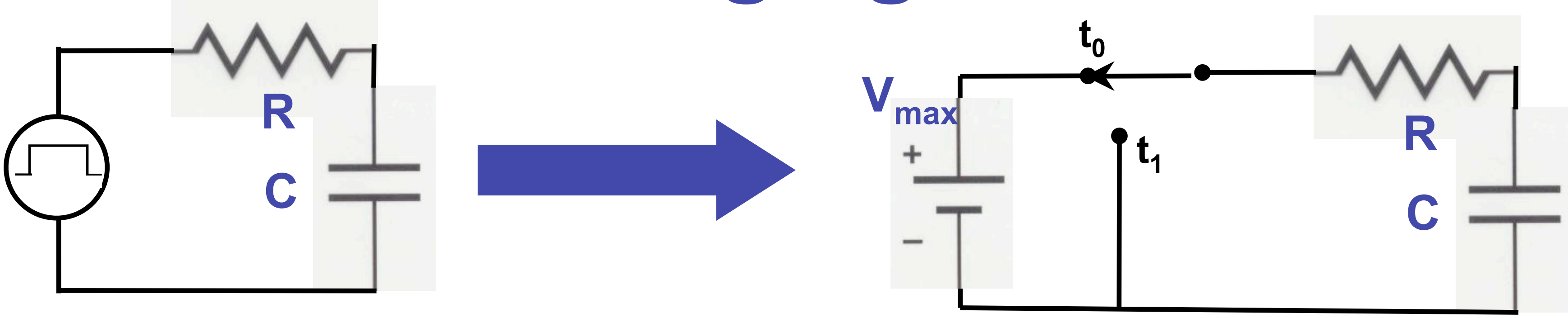
$$\sum_k \Delta V_k = \sum_j E_j$$

RC: charging



V_{max}
$V_c = \frac{q(t)}{C} = V_{max}\left(1 - e^{-t/RC}\right)$
V_{max}
$V_c(t)$
τ= RC time constant
$\tau_1 < \tau_2 < \tau_3$
0
Current
0
$i(t) = \frac{V_{max}}{R} e^{-t/RC}$

RC circuit: charging



Loop rule: $$V_{max} = V_R + V_C$$

$$V_{max} = iR + \frac{q}{C} = R\frac{dq}{dt} + \frac{q}{C}$$

$$q(t) = CV_{max}\left(1 - e^{-t/RC}\right)$$

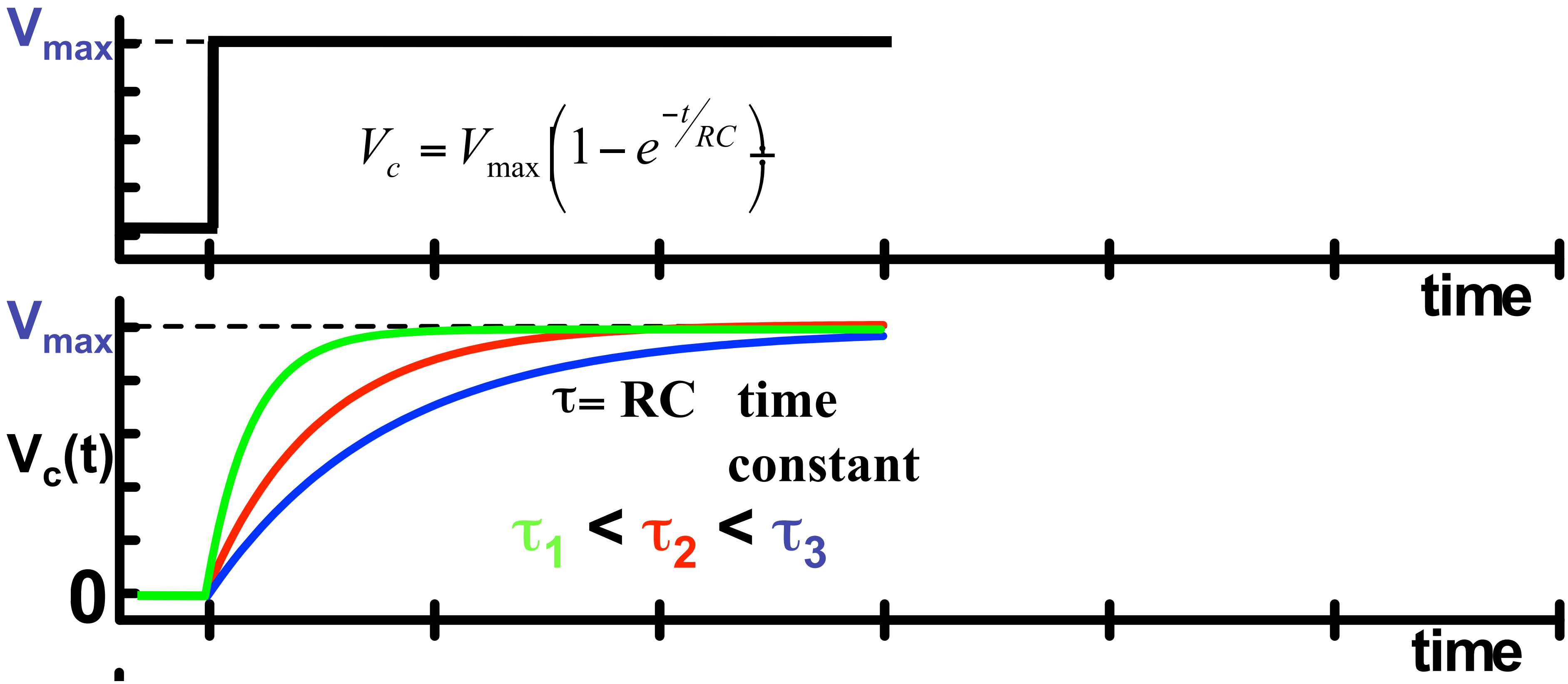
$$V_c = \frac{q(t)}{C} = V_{max}\left(1 - e^{-t/RC}\right)$$

$$i(t) = \frac{dq}{dt} = \frac{V_{max}}{R} e^{-t/RC}$$

$$\sum_k i_k = 0$$

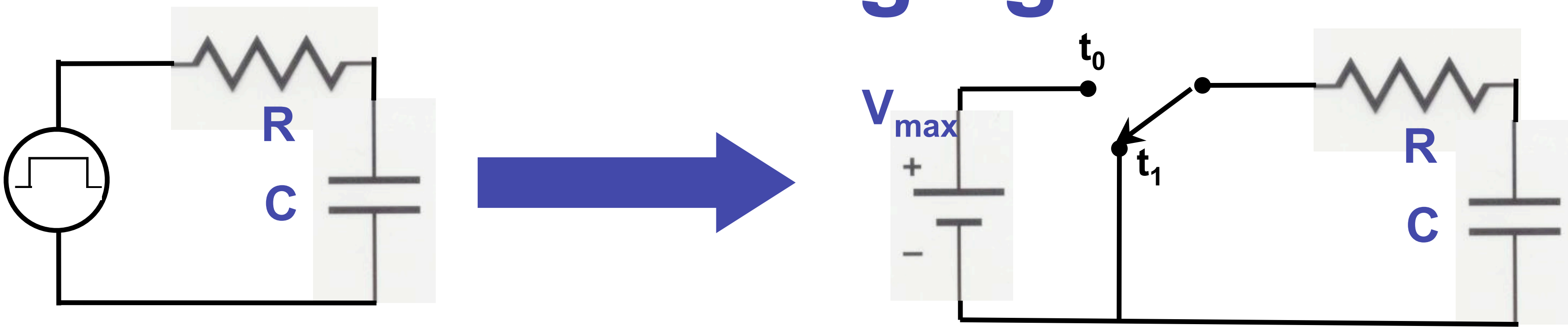
$$\sum_k \Delta V_k = \sum_j E_j$$

RC: charging



V_{max}
$V_c = V_{max}\left(1 - e^{-t/RC}\right)$
time
V_{max}
$V_c(t)$
0
τ= RC time constant
$\tau_1 < \tau_2 < \tau_3$
time

RC circuit: discharging



Loop rule: $$0 = R\frac{dq}{dt} + \frac{q}{C}$$

$$q(t) = CV_{max}e^{-t/RC}$$

$$V_C(t) = V_{max}e^{-t/RC}$$

$$i(t) = -\frac{V_{max}}{R}e^{-t/RC}$$

charging:

$$q(t) = CV_{max}\left(1 - e^{-t/RC}\right)$$

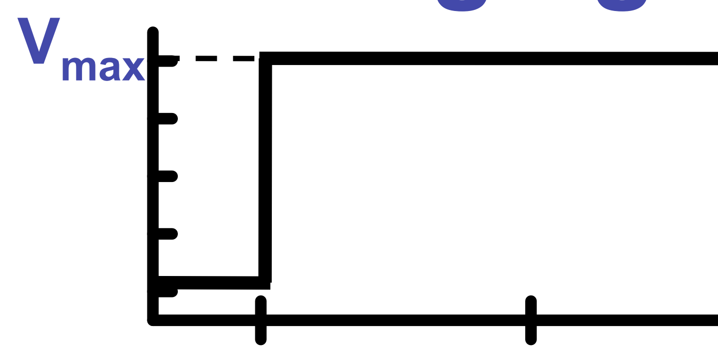
$$V_c = V_{max}\left(1 - e^{-t/RC}\right)$$

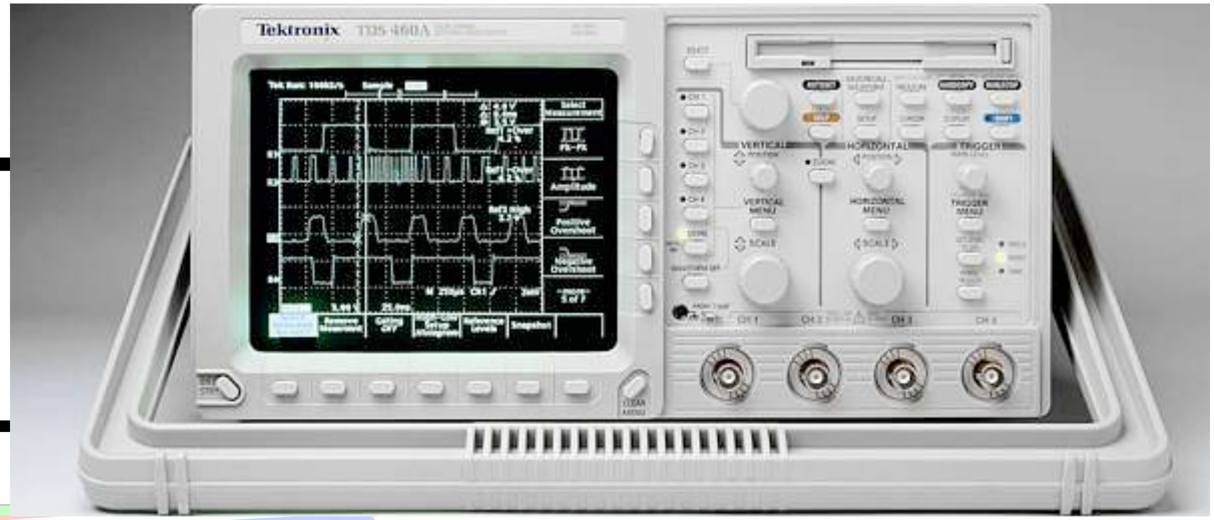
$$i(t) = \frac{V_{max}}{R}e^{-t/RC}$$

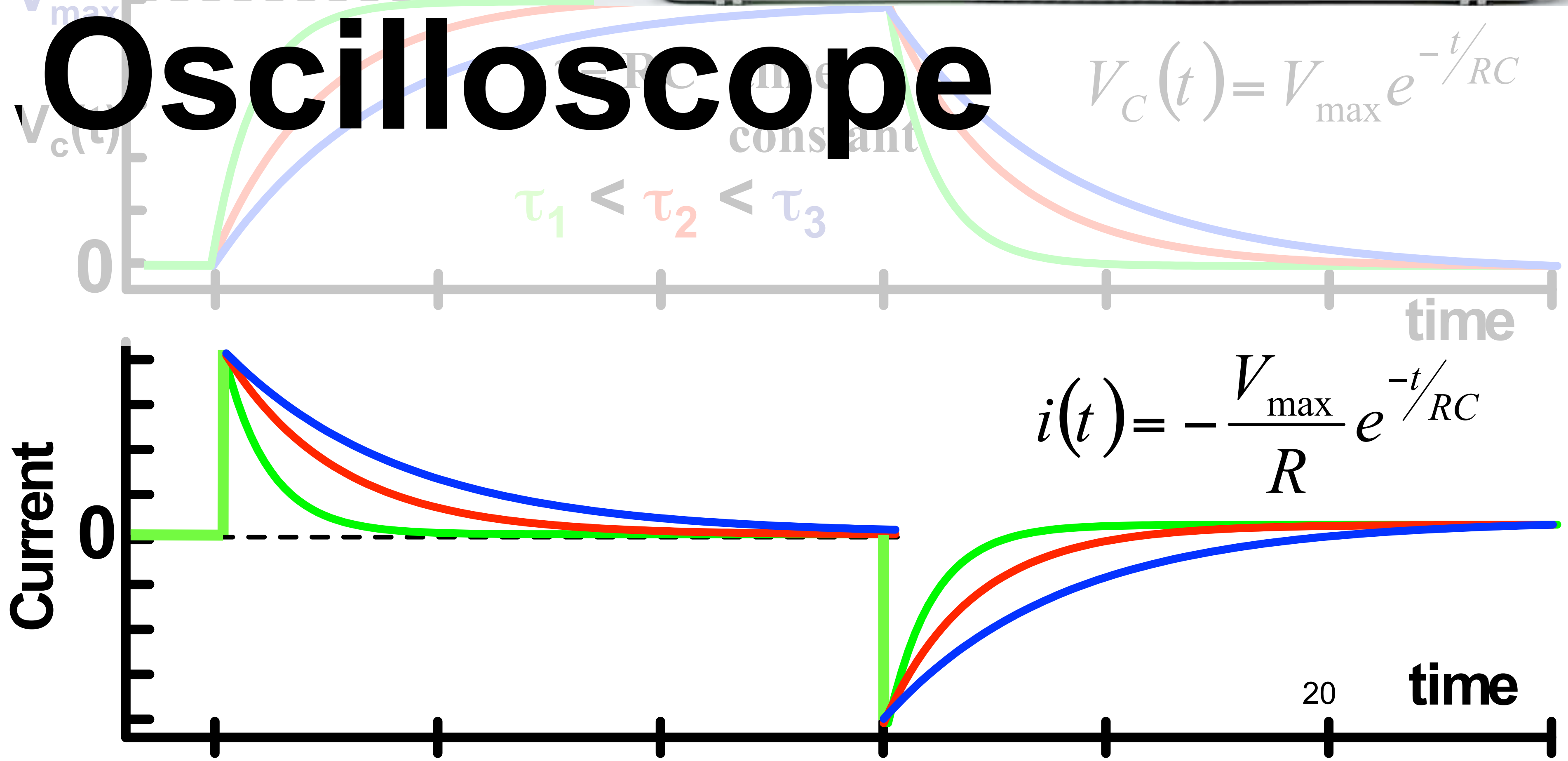
$$\sum_k i_k = 0$$

$$\sum_k \Delta V_k = \sum_j E_j$$

RC: charging





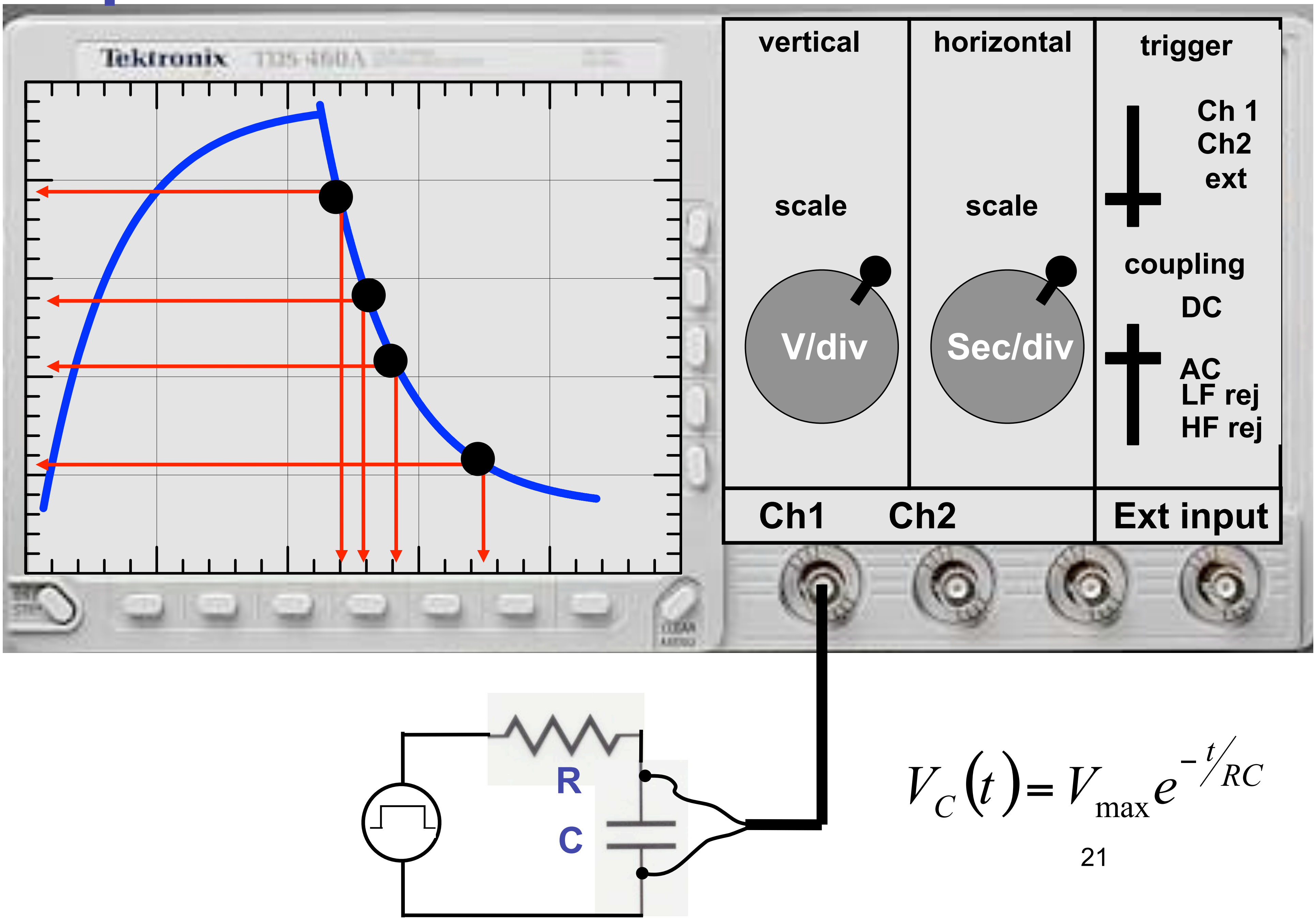


Oscilloscope

$$V_C(t) = V_{max} e^{-t/RC}$$

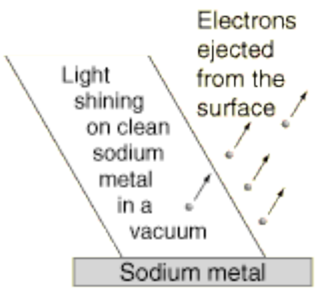
$$i(t) = -\frac{V_{max}}{R} e^{-t/RC}$$

Exp 1: RC circuits



$$V_C(t) = V_{max} e^{-t/RC}$$

Use Oscilloscope to get Planck's Constant in the Photoelectric Effect

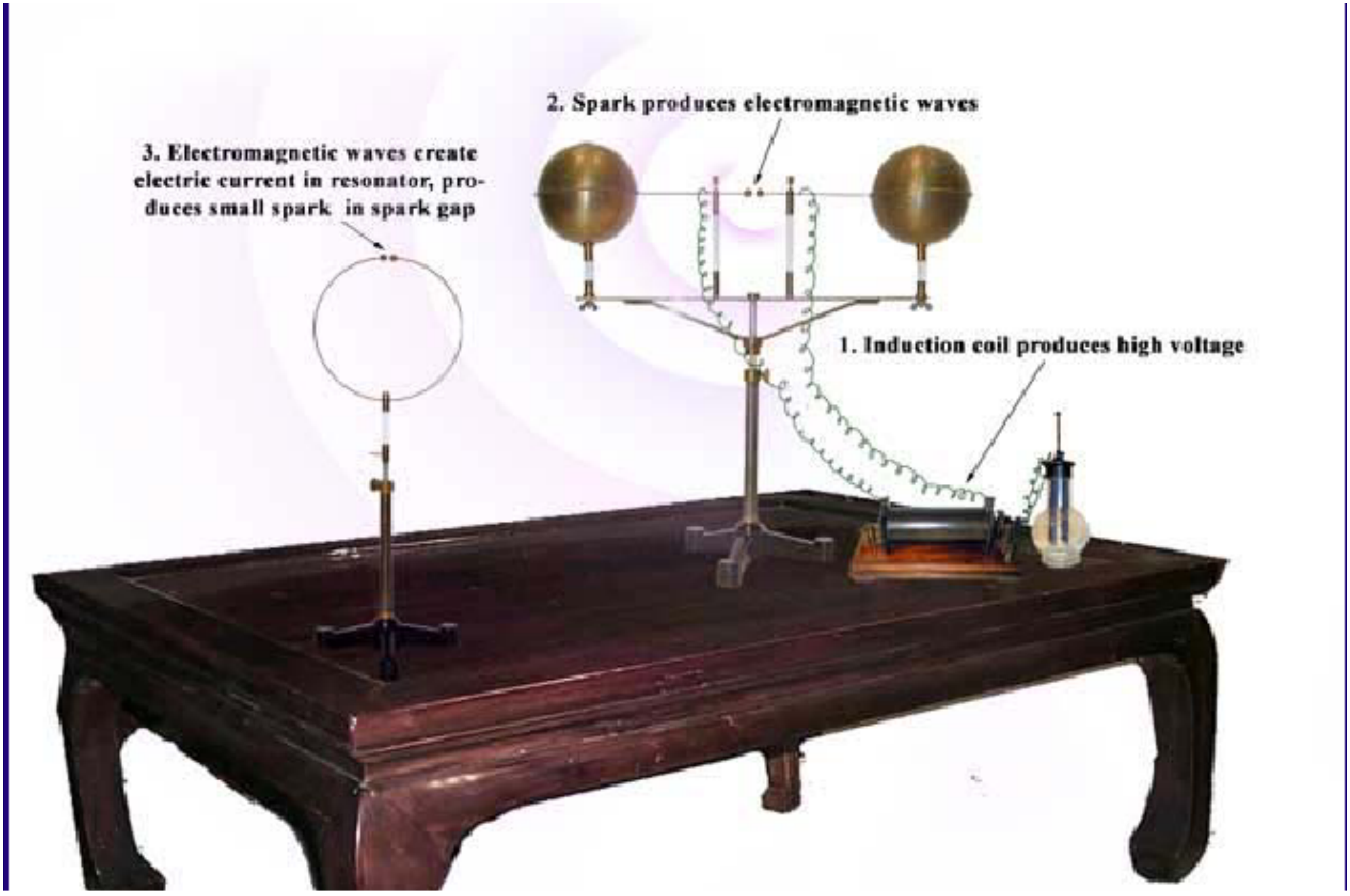


The Photoelectric Effect

- The explanation marked one of the major steps toward quantum theory.
- The remarkable aspects of the photoelectric effect when it was first observed were:

1. The electrons were emitted immediately - no time lag!
2. Increasing the intensity of the light increased the number of photoelectrons but not their maximum kinetic energy!
3. Red light will not cause the ejection of electrons, no matter what the intensity!
4. A weak violet light will eject only a few electrons, but their maximum kinetic energies are greater than those for intense light of longer wavelengths!

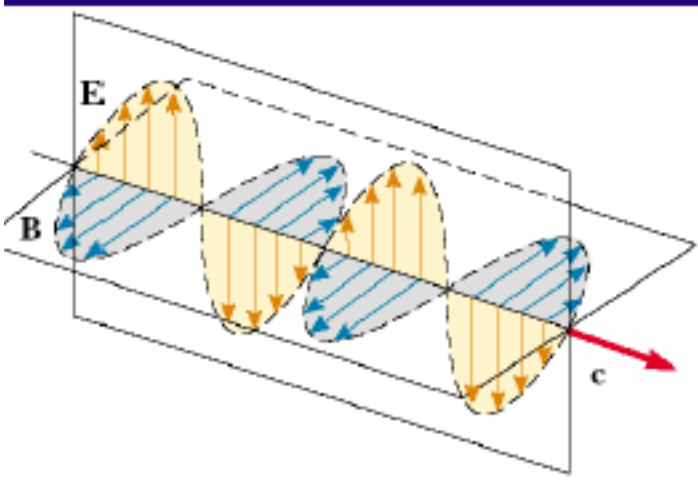
- The Photoelectric Effect was first observed by H. Hertz using a spark gap generator.
- He found he could increase the sensitivity of the gap by illumination with UV light



The Photo Electric Effect: Nobel Prize for Einstein

- Maxwell's Equations → EM Wave Properties
- Hertz & Electromagnetic Waves (Experiment)
- Description of Photoelectric Effect
  - Failure of classical physics (why?)
- Einstein's "Quantum" Interpretation inspired by Max Planck
- Bottomline :
  - How EM waves propagate
  - Interaction of EM waves with Matter
- How to prove that Einstein was right : Measure "h"
  - Find it is same as in Blackbody radiation

EM Waves



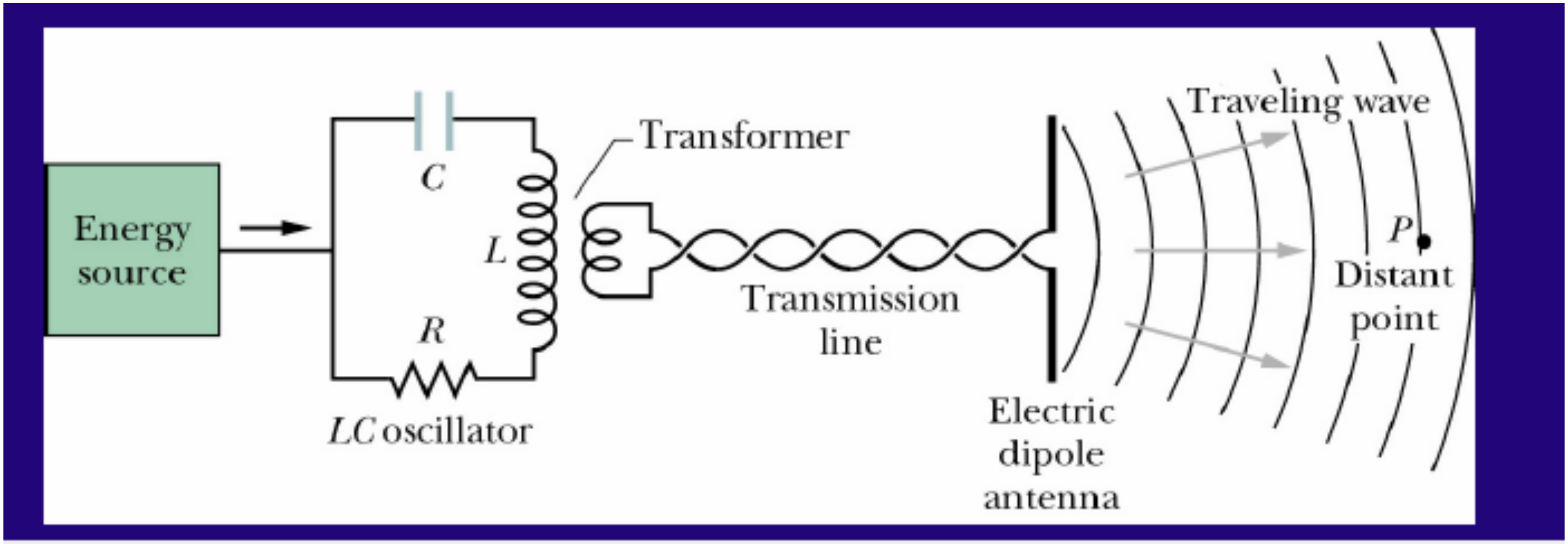
Energy Flow in EM Waves :

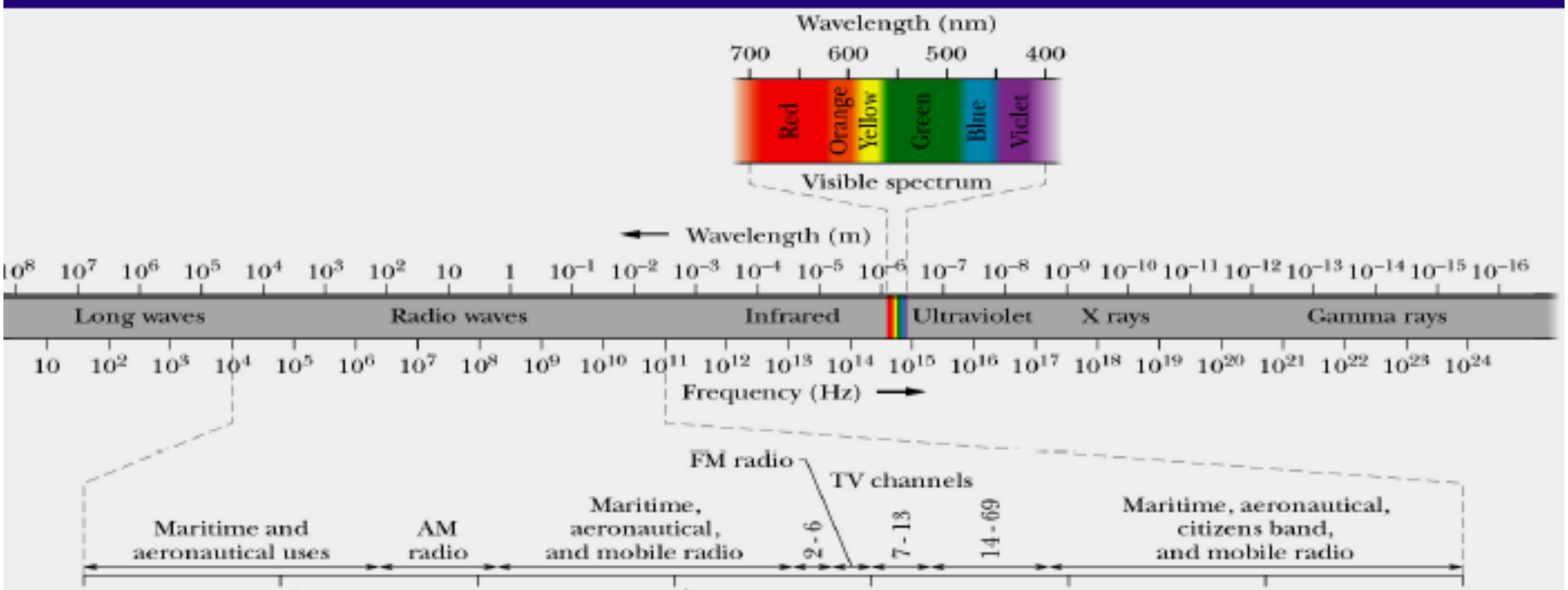
Poynting Vector $\vec{S} = \frac{1}{\mu_0}(\vec{E} \times \vec{B})$

Power incident on an area A $= \vec{S}.\vec{A} = \frac{1}{\mu_0}\left(AE_0 B_0 Sin^2(kx - \omega t)\right)$

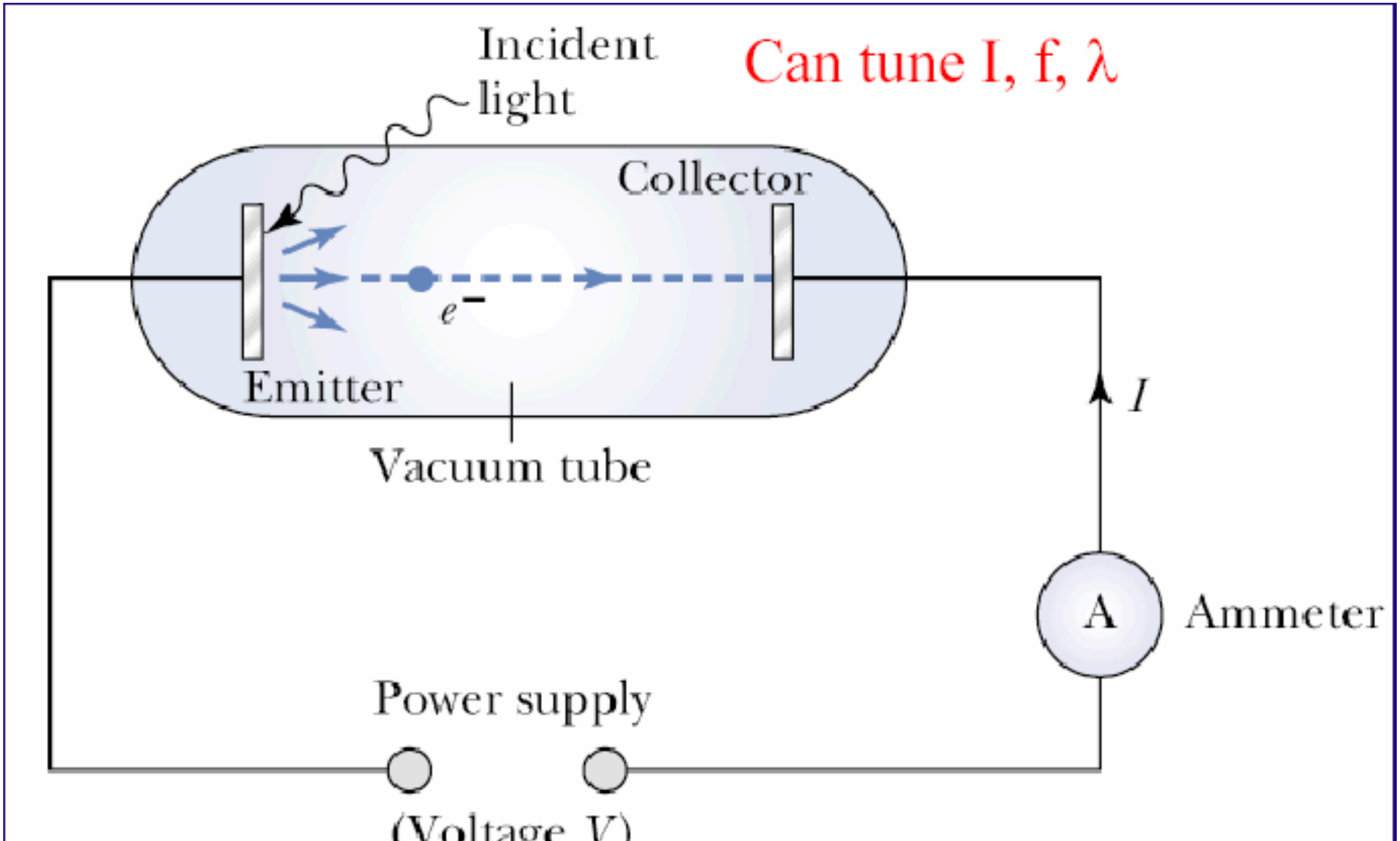
Intensity of Radiation I $= \frac{1}{2\mu_0 c} E_0^2$

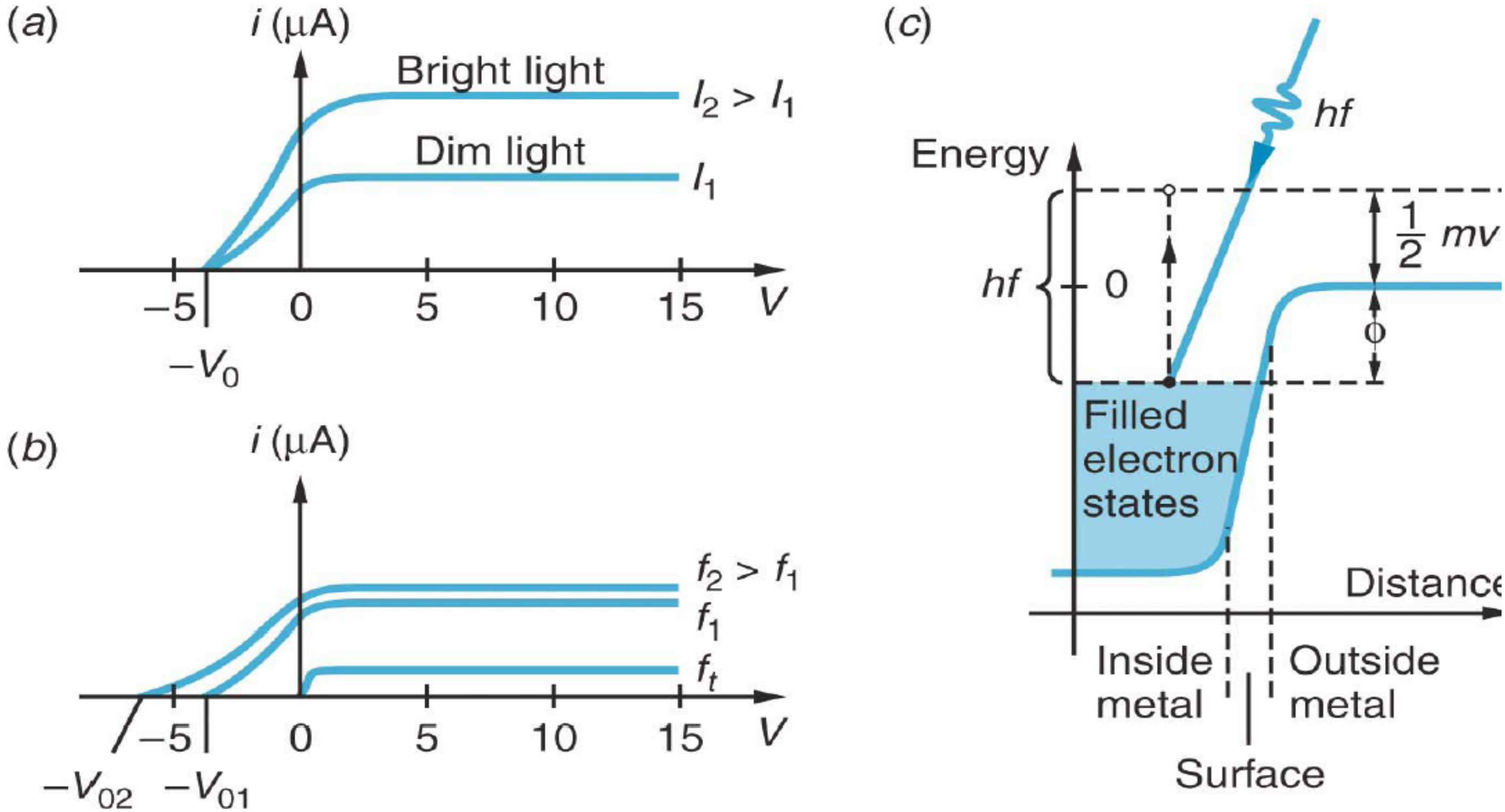
Larger the amplitude of Oscillation
More intense is the radiation


Energy source
C
L
R
LC oscillator
Transformer
Transmission line
Electric dipole antenna
Traveling wave
P
Distant point

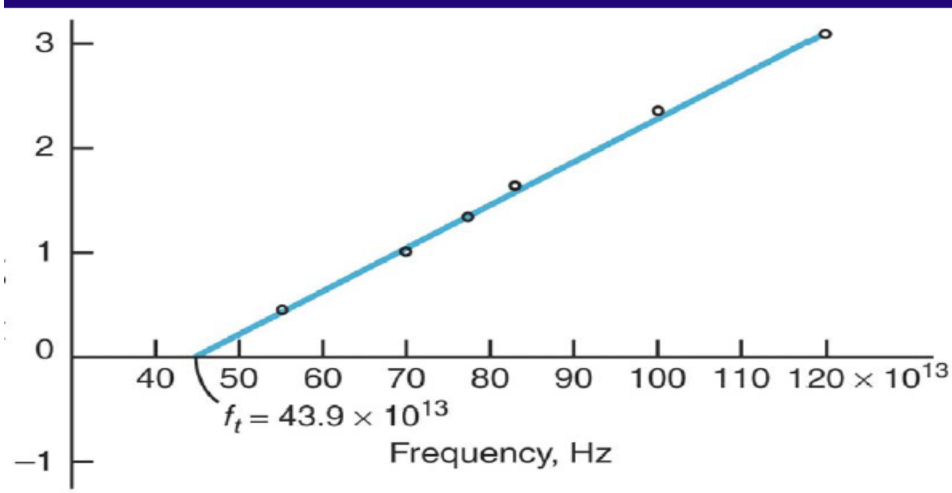

Wavelength (nm)
700 600 500 400
Red
Orange
Yellow
Green
Blue
Violet
Visible spectrum
Wavelength (m)
10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14} 10^{-15} 10^{-16}
Long waves
Radio waves
Infrared
Ultraviolet
X rays
Gamma rays
10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21} 10^{22} 10^{23} 10^{24}
Frequency (Hz)
FM radio
TV channels
Maritime and aeronautical uses
AM radio
Maritime, aeronautical, and mobile radio
2 - 6
7 - 13
14 - 69
Maritime, aeronautical, citizens band, and mobile radio

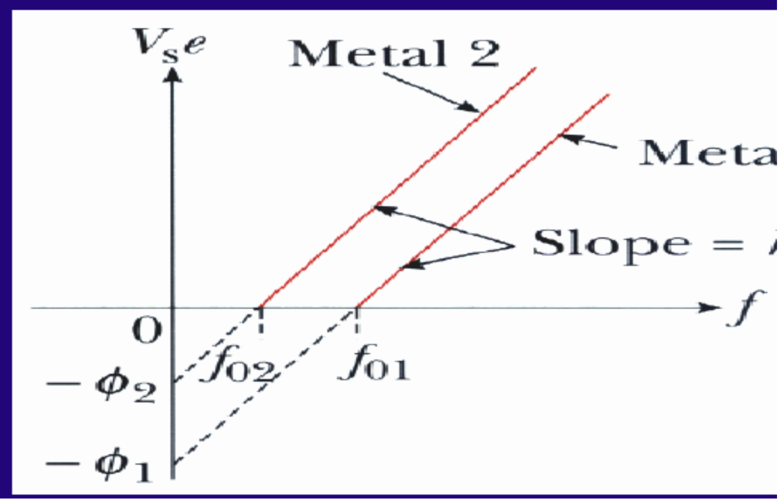
PE Experiment in 2DL

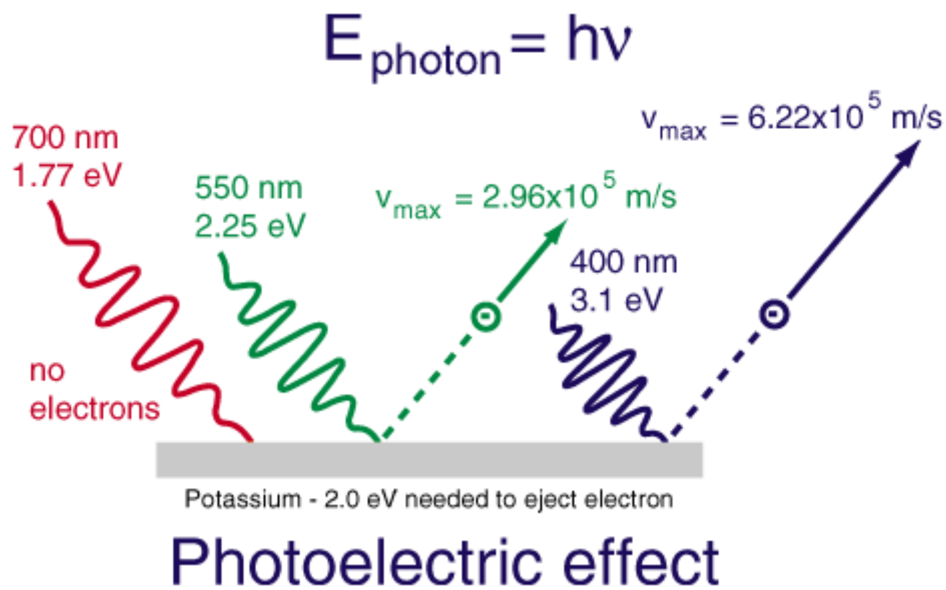



(a)
i (μA)
Bright light
$I_2 > I_1$
Dim light
I_1
−5
0
5
10
15
V
$-V_0$
(b)
i (μA)
$f_2 > f_1$
f_1
f_t
−5
0
5
10
15
V
$-V_{02}$
$-V_{01}$
(c)
hf
Energy
$\frac{1}{2}mv$
hf
0
φ
Filled electron states
Distance
Inside metal
Outside metal
Surface

$$V_s e = hf - \phi$$

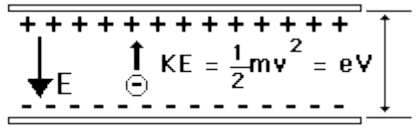

3
2
1
0
−1
40 50 60 70 80 90 100 110 120 × 10^13
$f_t = 43.9 \times 10^{13}$
Frequency, Hz


$V_s e$
Metal 2
Meta
Slope =
f
0
$-\phi_2$
$-\phi_1$
f_{02}
f_{01}



- Analysis of data from the photoelectric experiment showed that the energy of the ejected electrons was proportional to the frequency of the illuminating light.
- This showed that whatever was knocking the electrons out had an energy proportional to light frequency.
- This showed that the interaction must be like that of a particle which gave all of its energy to the electron!
- This fit in well with Planck's hypothesis that light could exist only in discrete bundles with energy E = hf

An Aside on eV



$E = qV = (1.6 \times 10^{-19}\ C)(1\ \frac{J}{C})$

$1\ \text{electron volt} = 1.6 \times 10^{-19}\ J$

e = electron charge = 1.6×10^{-19} C
V = voltage

A convenient energy unit, for atomic and nuclear processes, is the energy given to an electron by accelerating it through 1 volt of electric potential difference. The work done on the charge is given by the charge times the voltage difference.

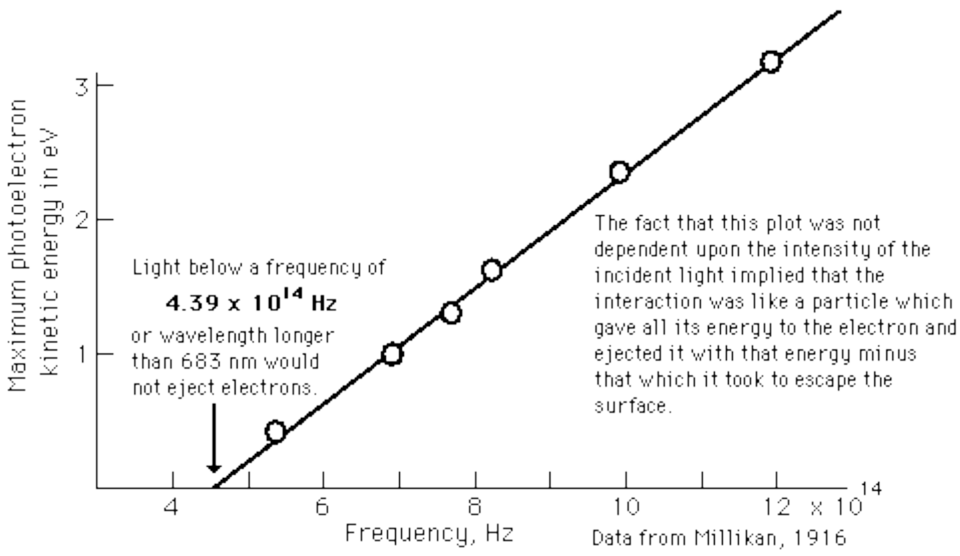
- The abbreviation for electron volt is eV.

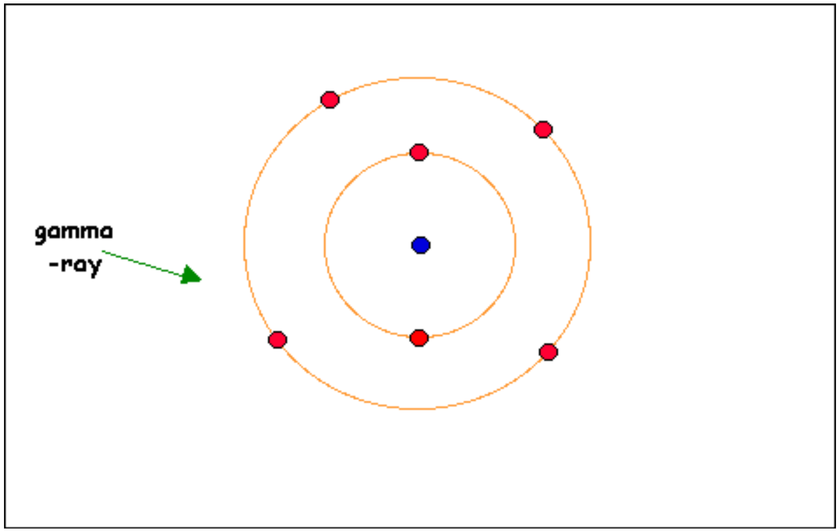
Photoelectric Effect

Early Photoelectric Effect Data

- Electrons ejected from a sodium metal surface were measured as an electric current. Finding the opposing voltage it took to stop all the electrons gave a measure of the maximum kinetic energy of the electrons in electron volts.

- The minimum energy required to eject an electron from the surface is called the photoelectric work function. The threshold for this element corresponds to a wavelength of 683 nm. Using this wavelength in the Planck relationship gives a photon energy of 1.82 eV.





- Accepted Value of h=6.626 × 10^{-34} J.sec
- You measure freq = 45 THz with uncertainty:
- dF=4.5 THz
- What is best estimate for the Uncertainty in Energy = hF?
- E = 3.0 ± 0.3 × 10^{-20} J

$$V_s e = hf - \phi$$