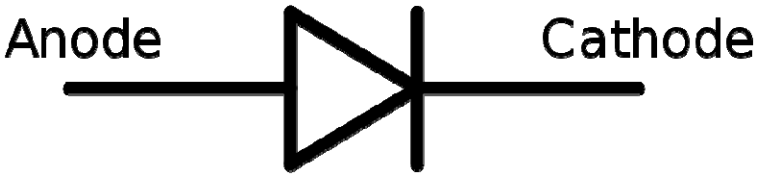
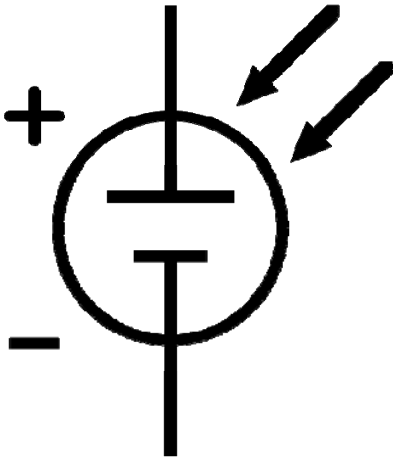
Current-voltage curves in semiconductor diodes and solar cells

Week of Feb. 15, 2010

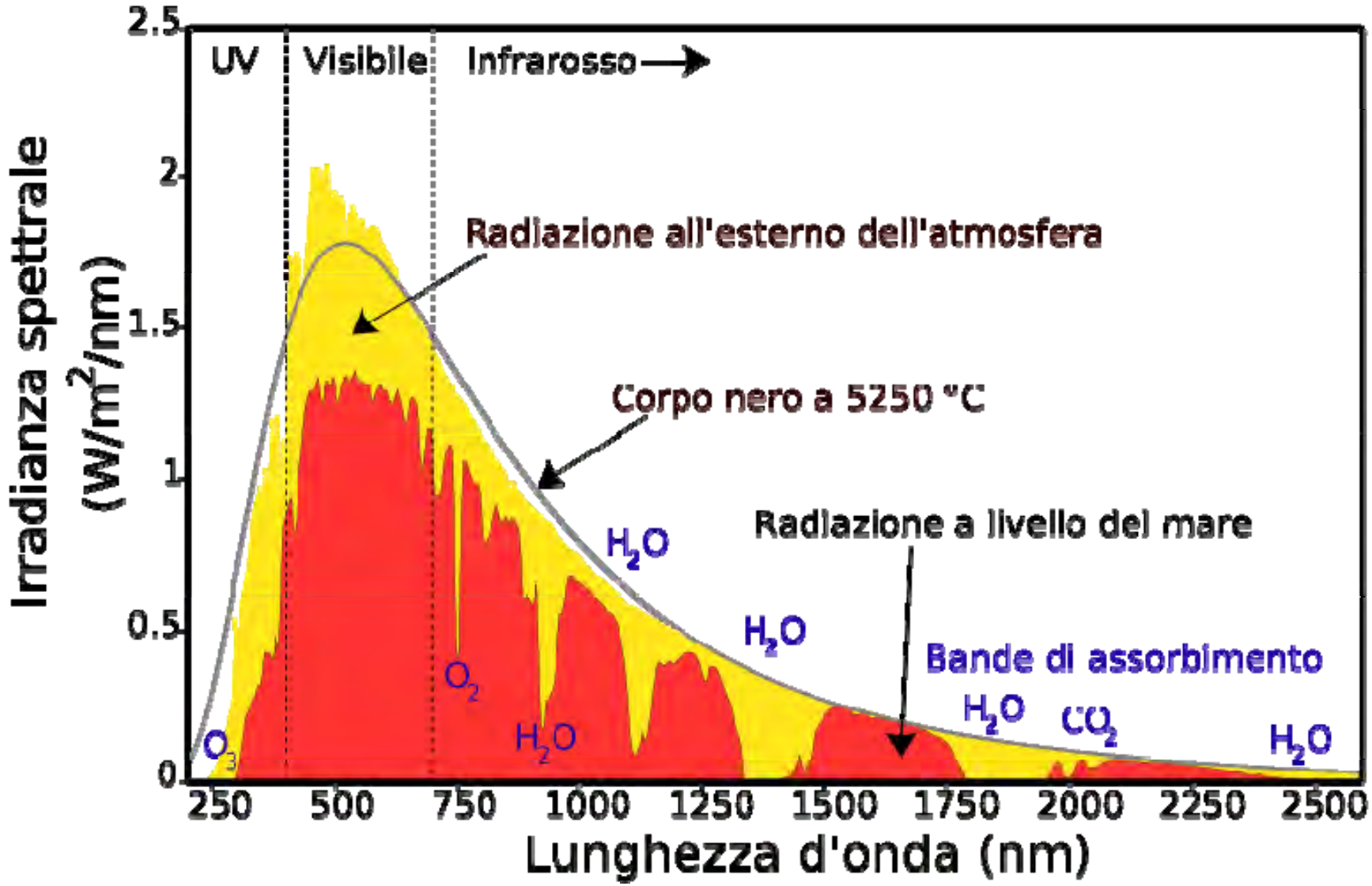




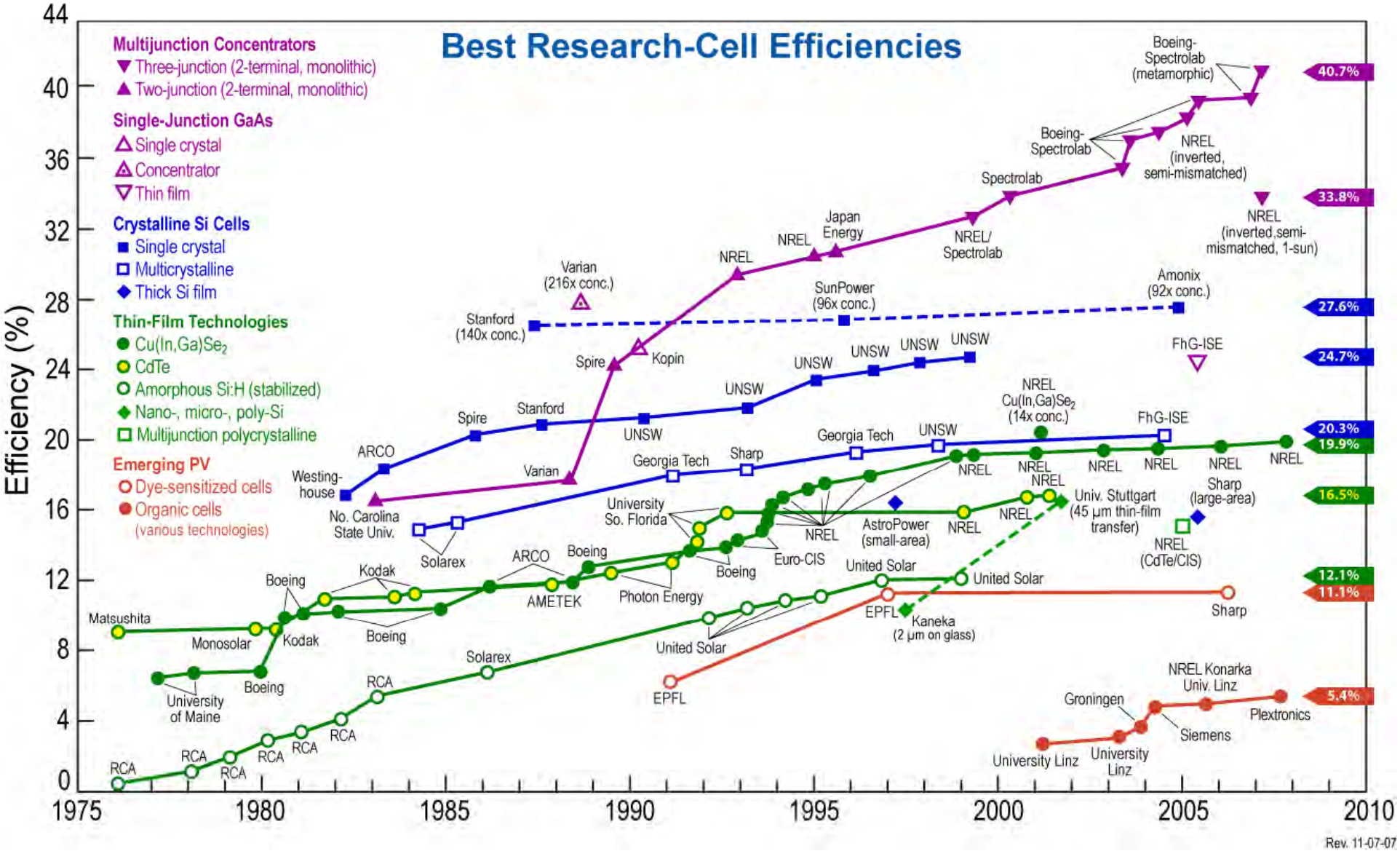
Modern Physics Laboratory
(Physics 6180/7180)

The University of Toledo
Instructor: Randy Ellingson

Solar spectrum



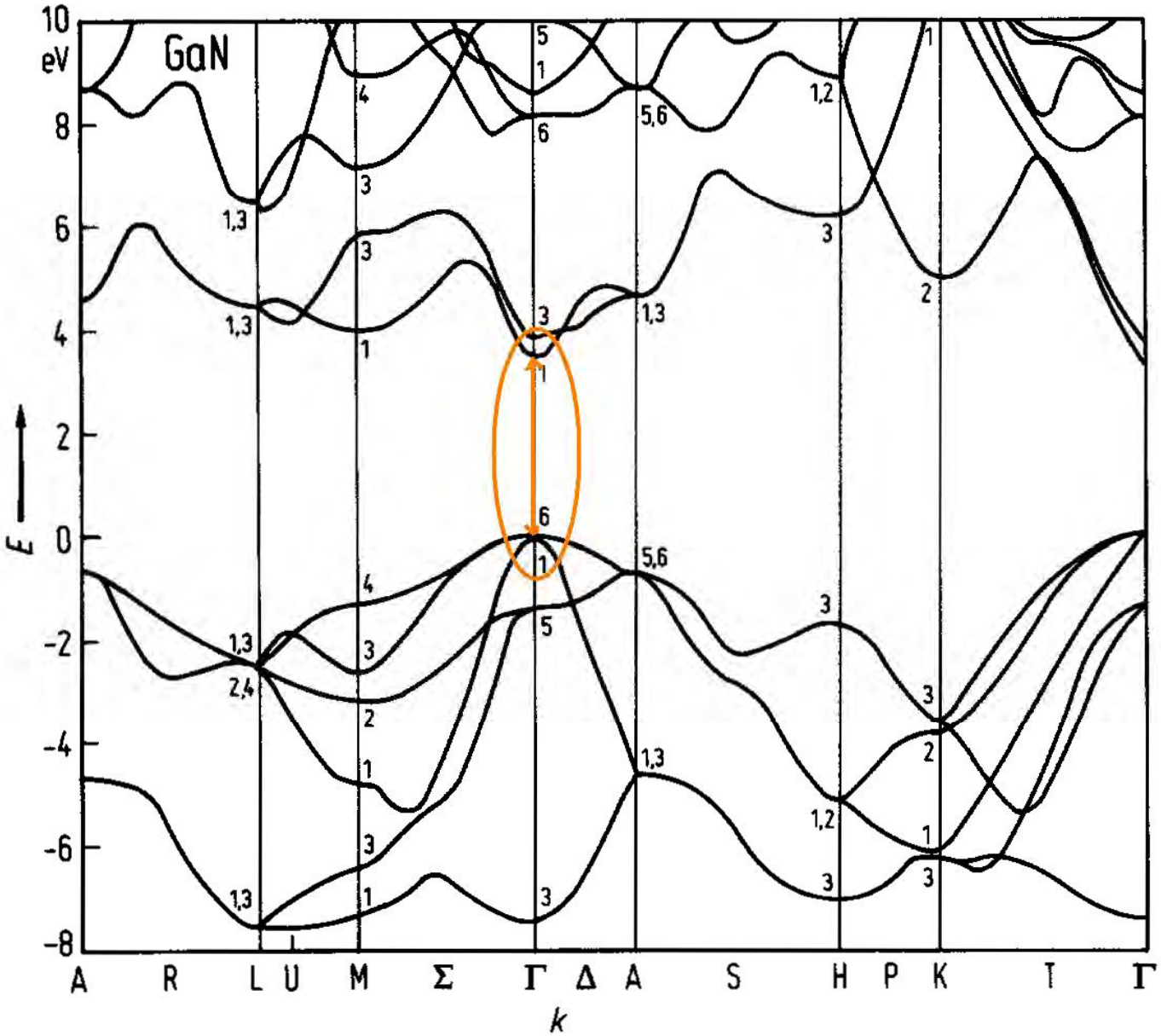
Solar cell efficiency trends



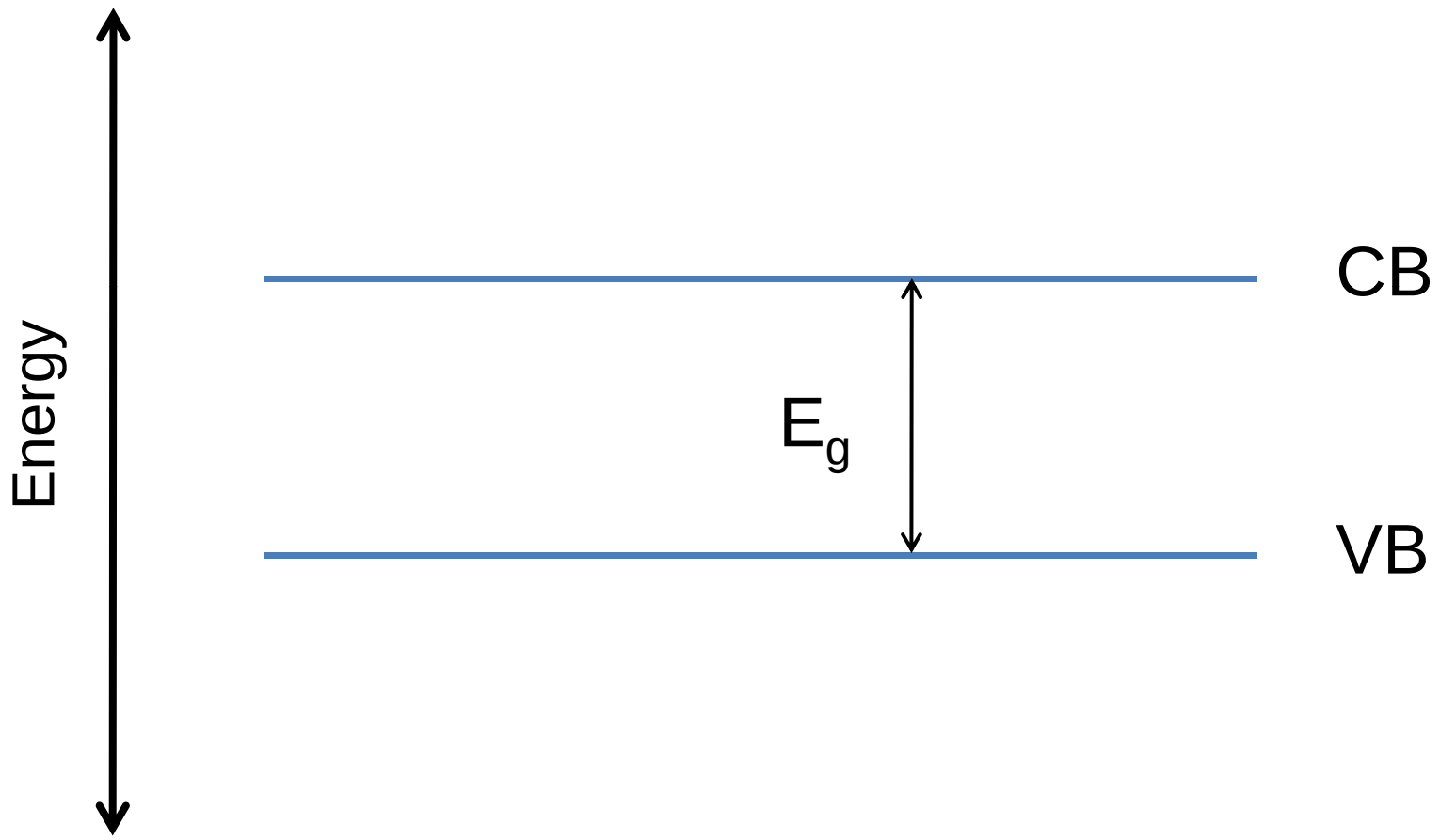
Semiconductor concepts

- Bandgap, conduction band, valence band, band edges
- Electrons and holes
- Mobility
- T = 0 behavior, thermal excitation or population (Fermi distribution)
- Doping
- P-N junction
- Rectification (diode behavior)
- I-V Measurements

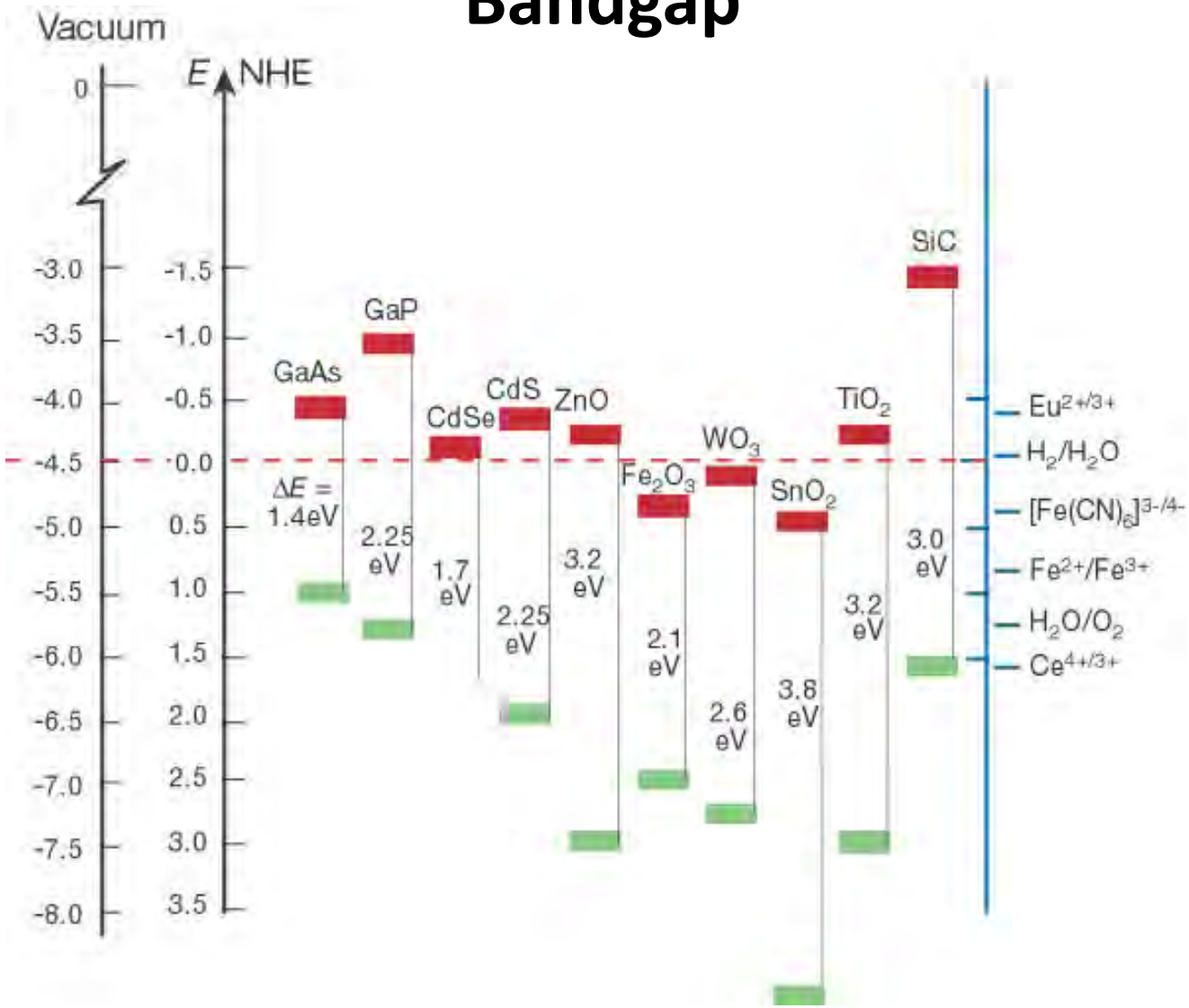
Bandgap (complicated)



Bandgap (simplified)



Bandgap



"Photoelectrochemical cells"
Michael Grätzel
Nature **414**, 338-344(15 Nov. 2001)
doi:10.1038/35104607

Mobility

Adapted from Wikipedia, the free encyclopedia

Mobility is a quantity relating the drift velocity of a charge carrier to the applied electric field across a material, according to the formula:

$$v_d = \mu E$$

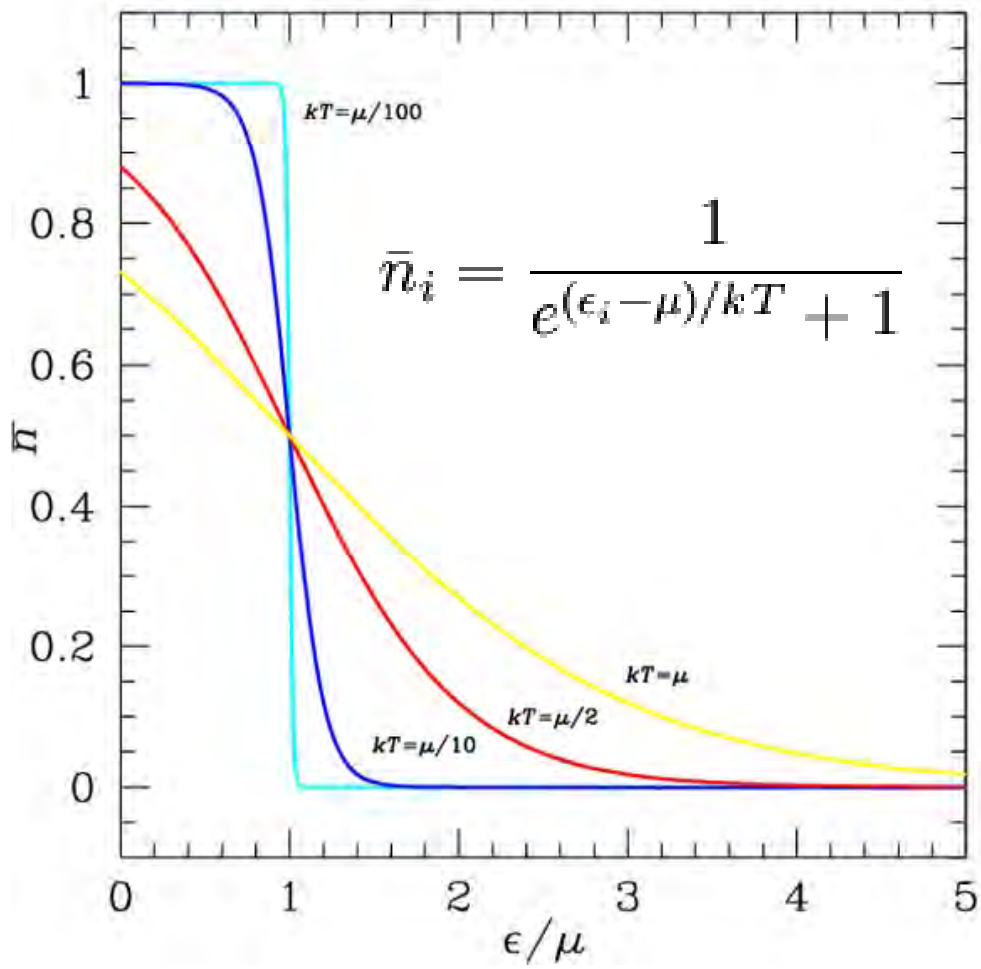
where

v_d is the drift velocity in m/s;
E is the applied electric field in V/m;
μ is the mobility in $m^2/(V \cdot s)$.

A mixed mobility unit of 1 $cm^2/(V \cdot s)$ = 0.0001 $m^2/(V \cdot s)$ is also often used. It is the application for electrons of the more general phenomenon of electrical mobility of charged particles in a fluid under an applied electric field.

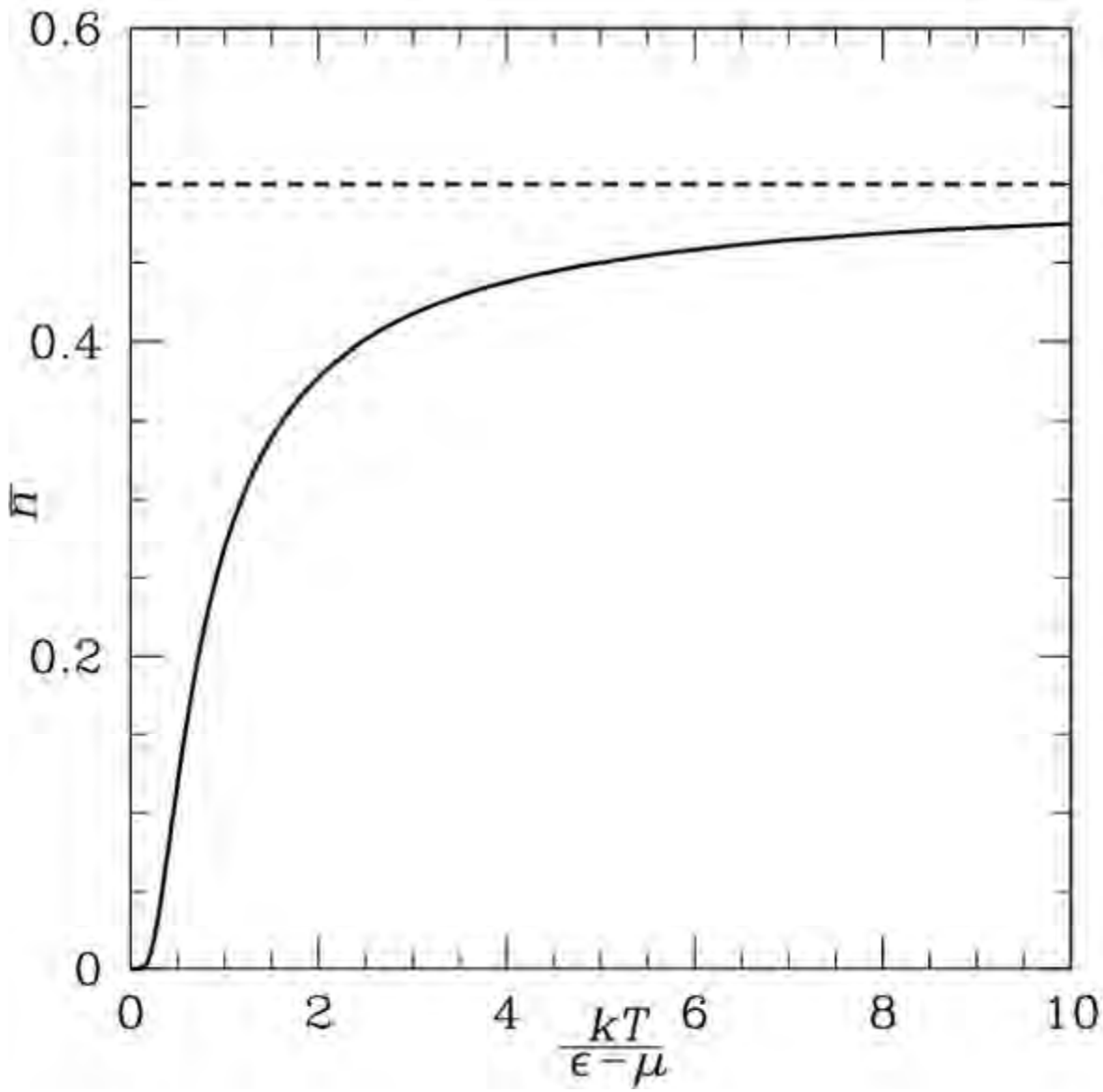
In semiconductors, mobility can apply to electrons as well as to holes.

Fermi-Dirac distribution



Energy dependence. More gradual at higher T. $\bar{n}_i$ =0.5 when ε = μ. Not shown is that μ decreases for higher T.[13]

Fermi distribution ($\varepsilon > \mu$)

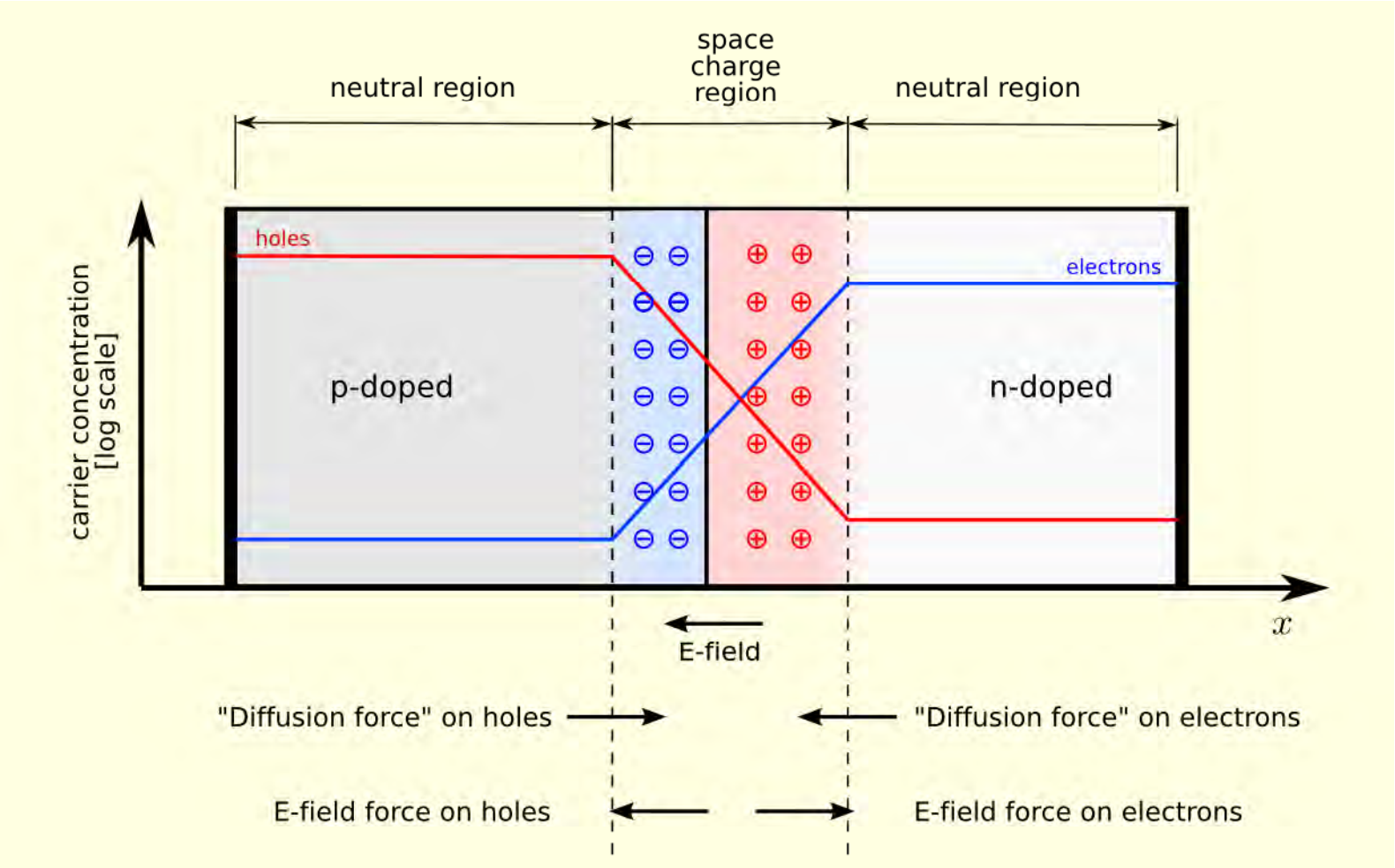


Semiconductor Doping

Paraphrased from Wikipedia, the free encyclopedia

In semiconductor production, **doping** is the process of intentionally introducing impurity atoms into an extremely pure (also referred to as *intrinsic*) semiconductor to change its electrical properties. The impurity atoms chosen depend on the specific type of semiconductor. Lightly- and moderately-doped semiconductors are referred to as *extrinsic* (i.e., intentionally doped). A semiconductor doped to such high levels that it acts more like a conductor (i.e., a metal, with many free electrons) than a semiconductor is referred to as *degenerate*.

P-N Junction (at equilibrium)



Shockley diode equation

The *Shockley ideal diode equation* or the *diode law* (named after transistor co-inventor William Bradford Shockley) gives the *I*–*V* characteristic of an ideal diode in either forward or reverse bias (or no bias). The equation is:

$$I = I_S(e^{V_D/(nV_T)} - 1)$$

I is the diode current,
I_S is the reverse bias saturation current,
V_D is the voltage across the diode,
V_T is the thermal voltage, and
n is the ideality factor, which varies from about 1 to 2 depending on the fabrication process and semiconductor material and in many cases is assumed to be approximately equal to 1 (in which case the notation n is omitted).

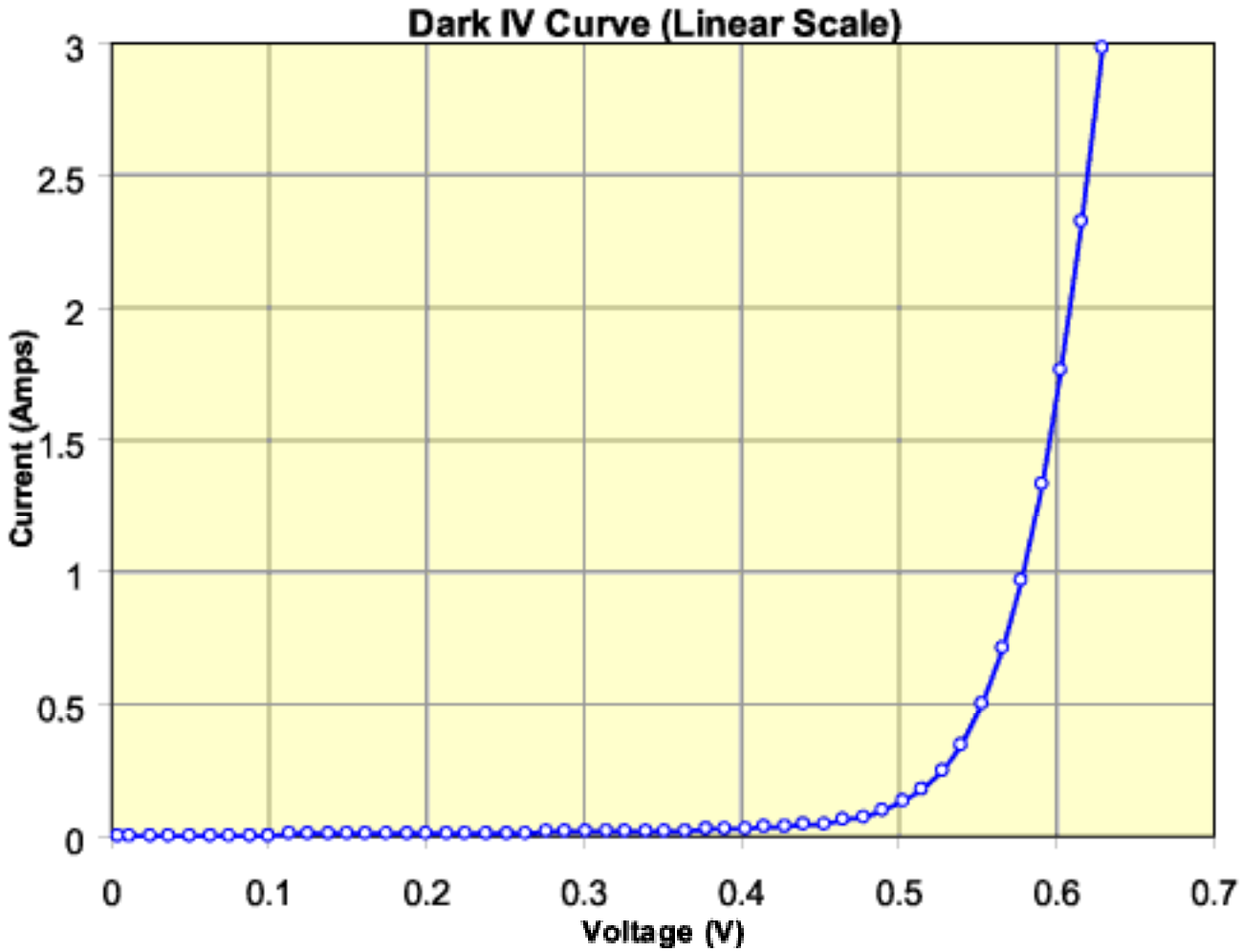
from Wikipedia.org

Thermal voltage?

$$V_T = \frac{k_B T}{q}$$

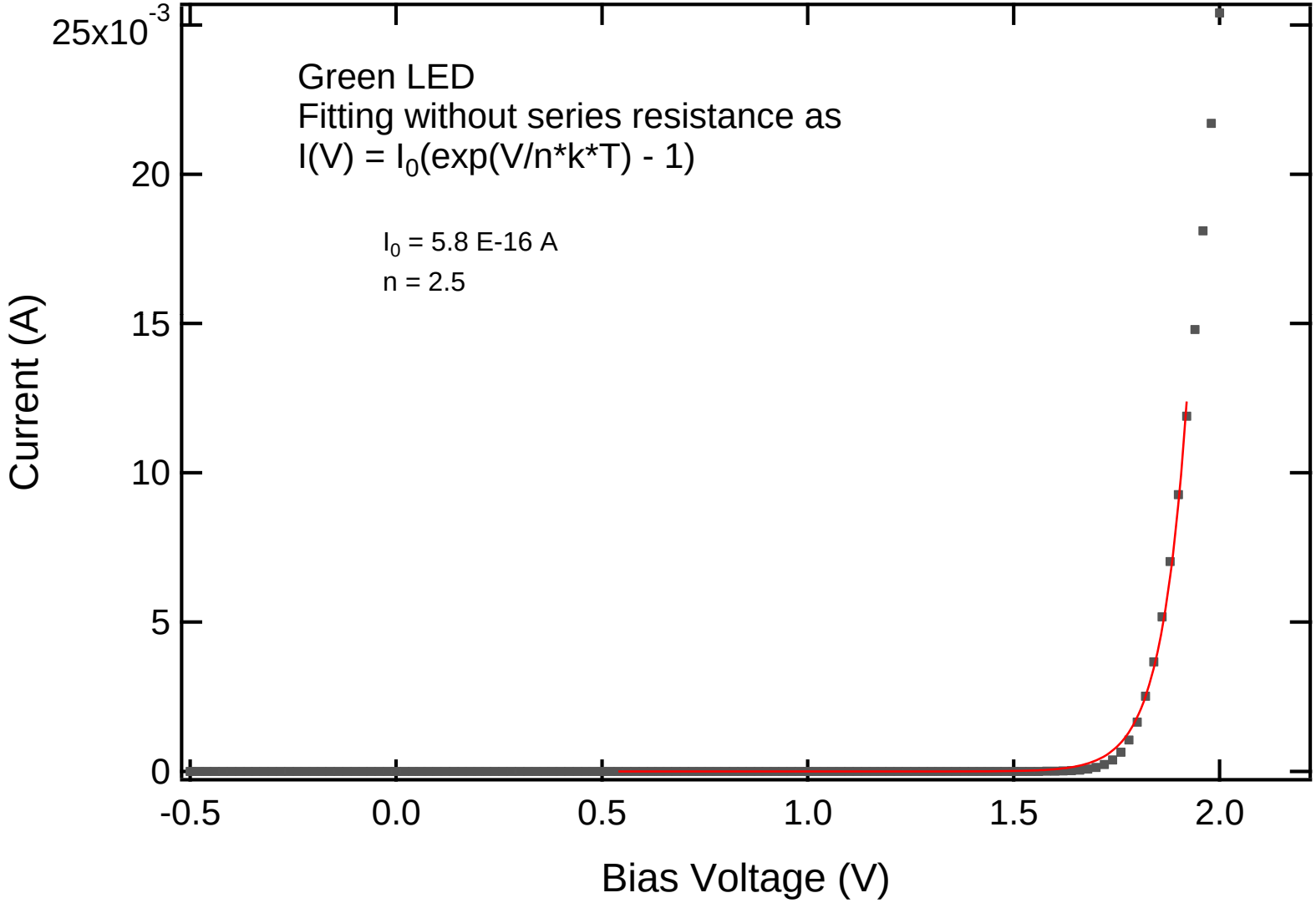
approximately 25.85 mV at 300 K

Dark I-V measurement (solar cell)

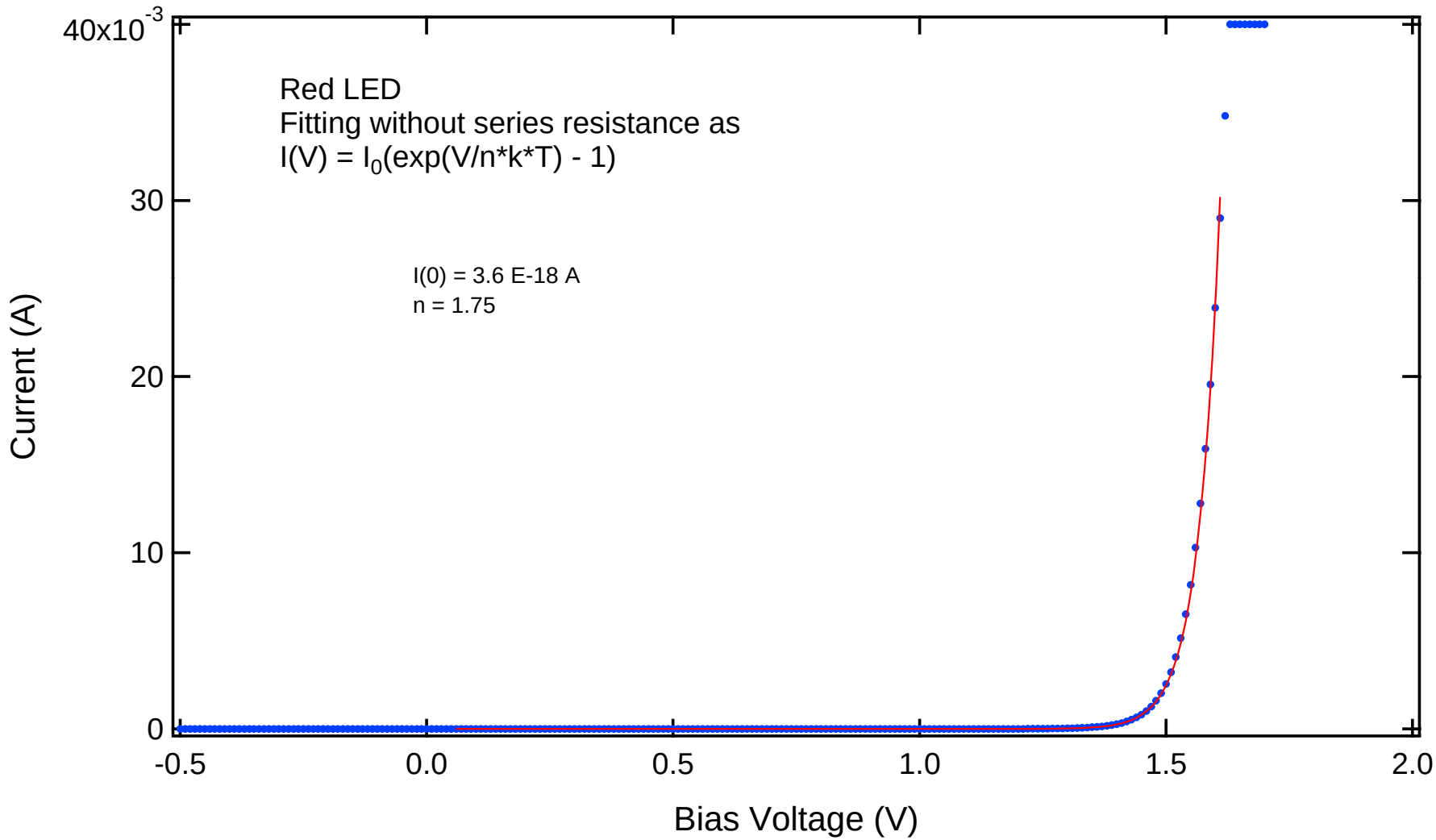


from pvcdrom.pveducation.org

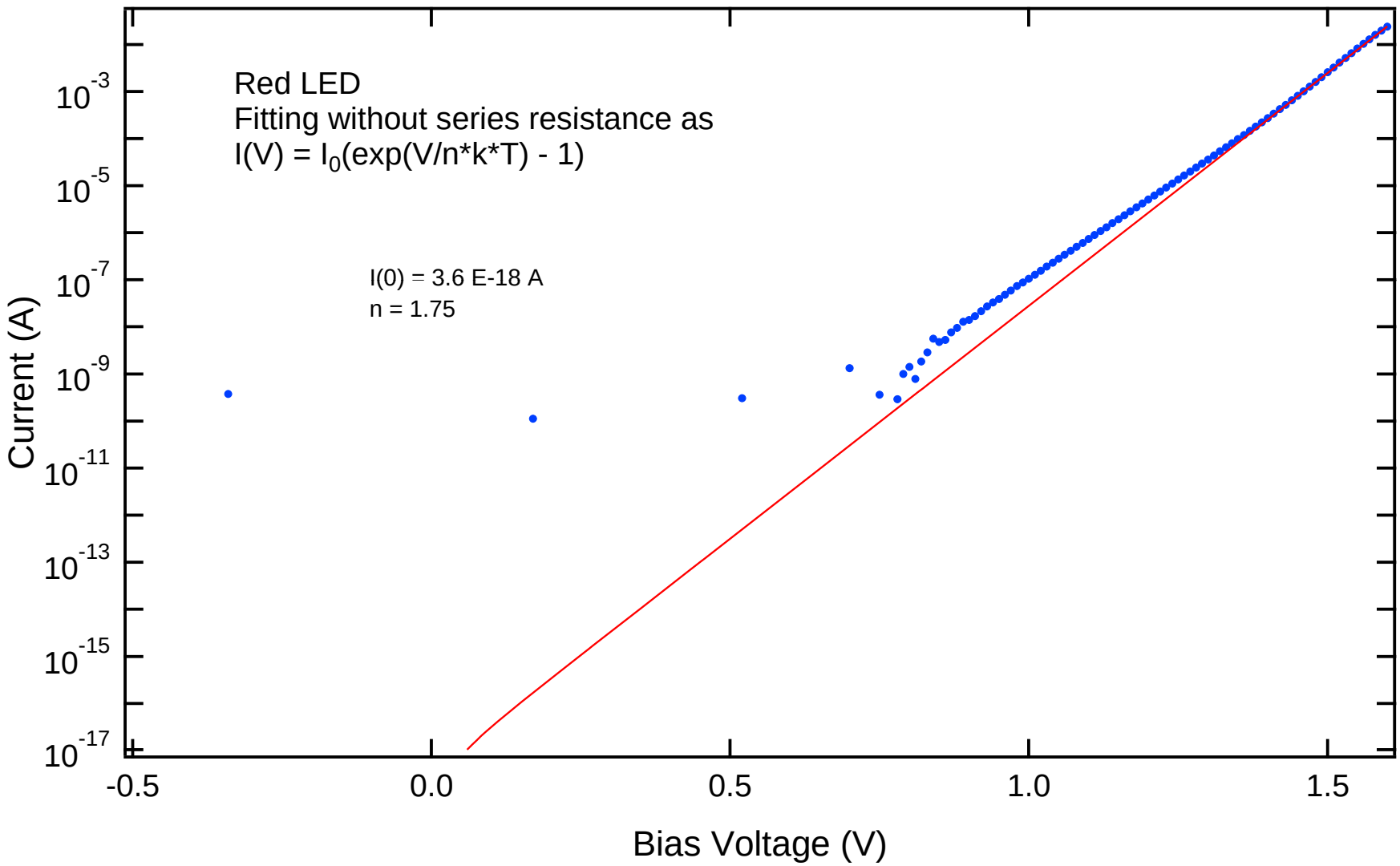
Green LED data



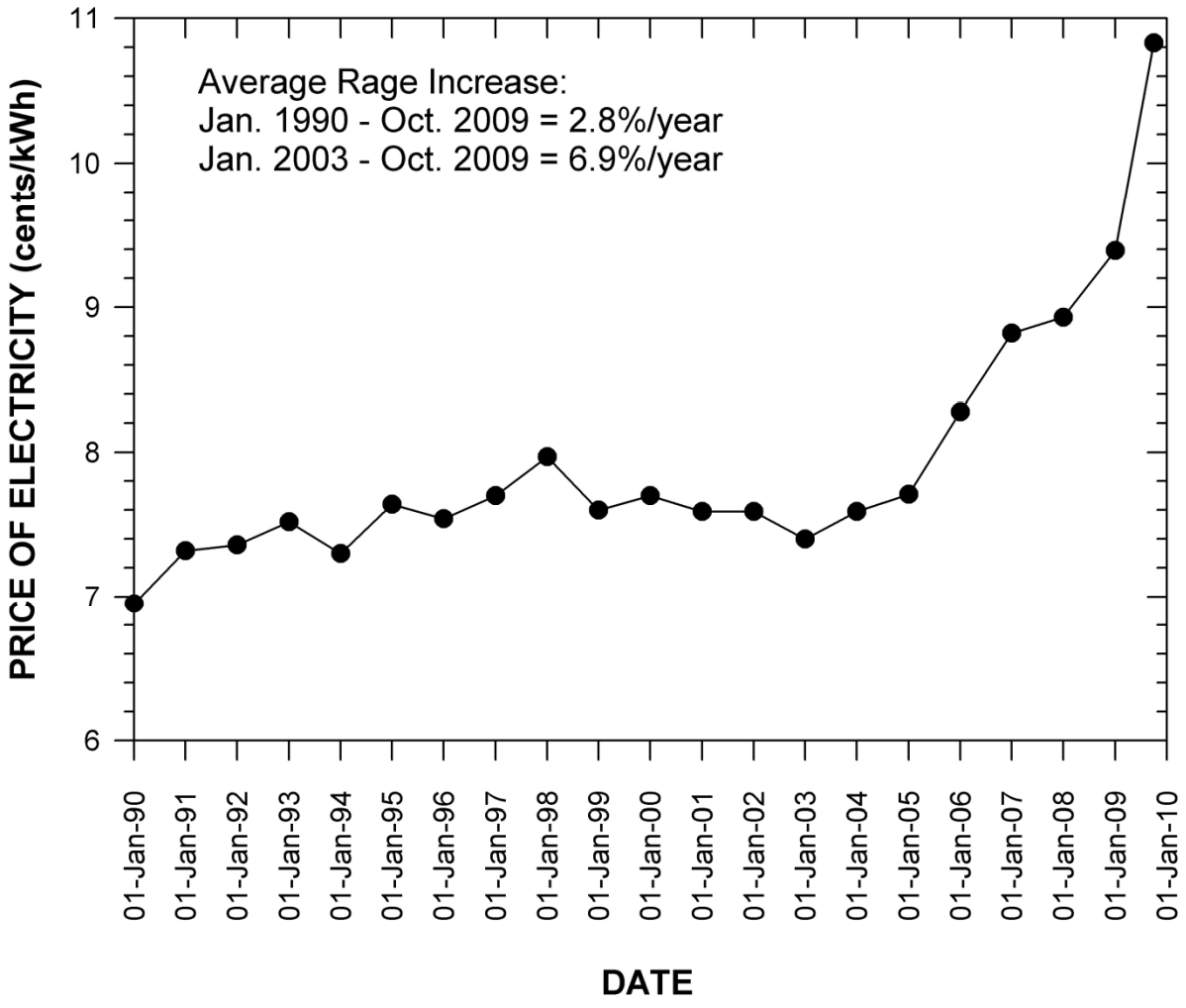
Red LED data


Red LED
Fitting without series resistance as
I(V) = I0(exp(V/n*k*T) - 1)
I(0) = 3.6 E-18 A
n = 1.75
40x10-3
30
20
10
0
Current (A)
-0.5
0.0
0.5
1.0
1.5
2.0
Bias Voltage (V)

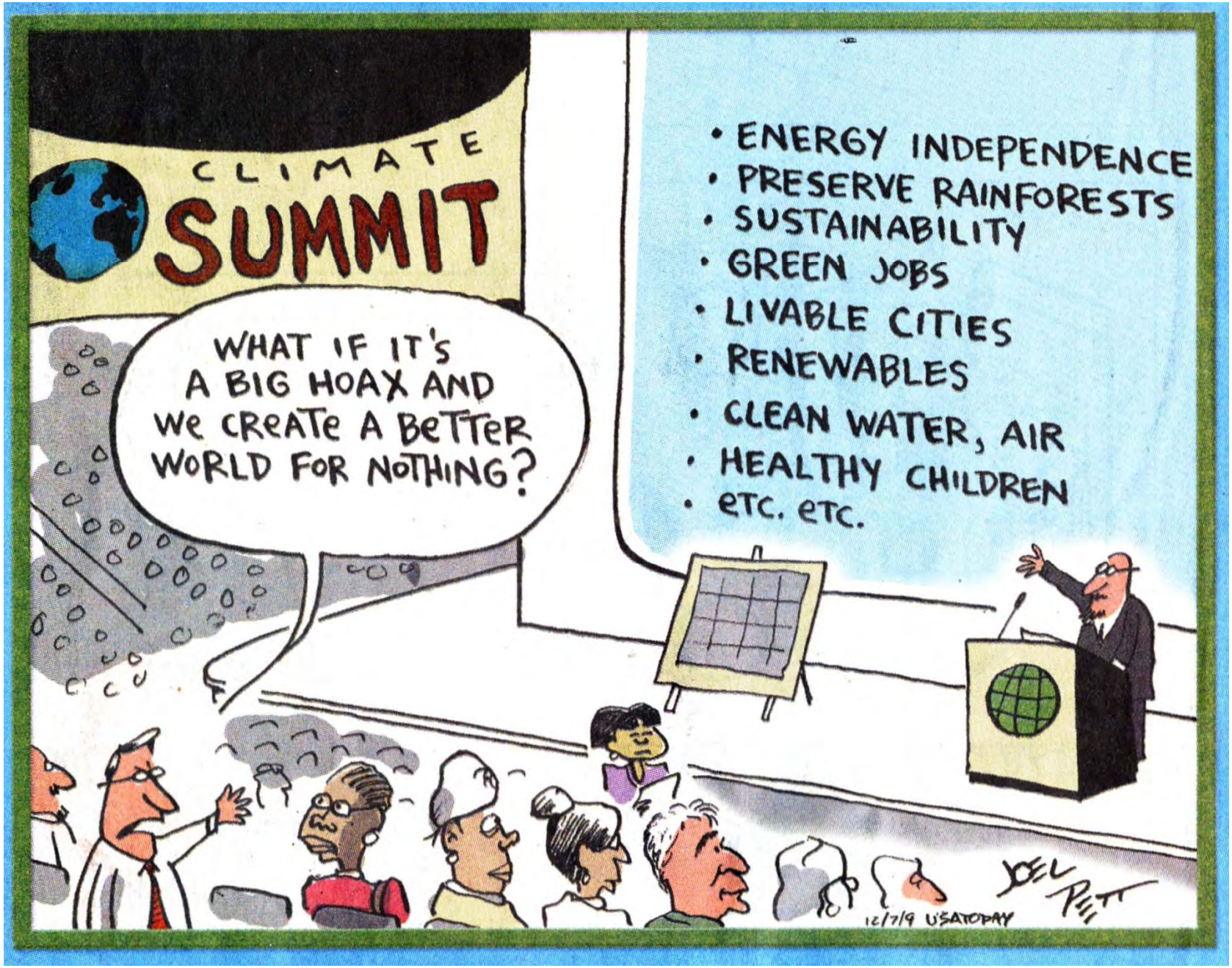
Red LED data


Red LED
Fitting without series resistance as
I(V) = I0(exp(V/n*k*T) - 1)
I(0) = 3.6 E-18 A
n = 1.75
Current (A)
10-3
10-5
10-7
10-9
10-11
10-13
10-15
10-17
-0.5
0.0
0.5
1.0
1.5
Bias Voltage (V)

OHIO STATE-WIDE
AVERAGE RETAIL RESIDENTIAL
PRICE FOR ELECTRICITY



Data Source: Energy Information Administration, U.S. Dept. of Energy
Analysis by Brooks Martner


CLIMATE
SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• ETC. ETC.
12/7/9 USATODAY
JOEL PETT