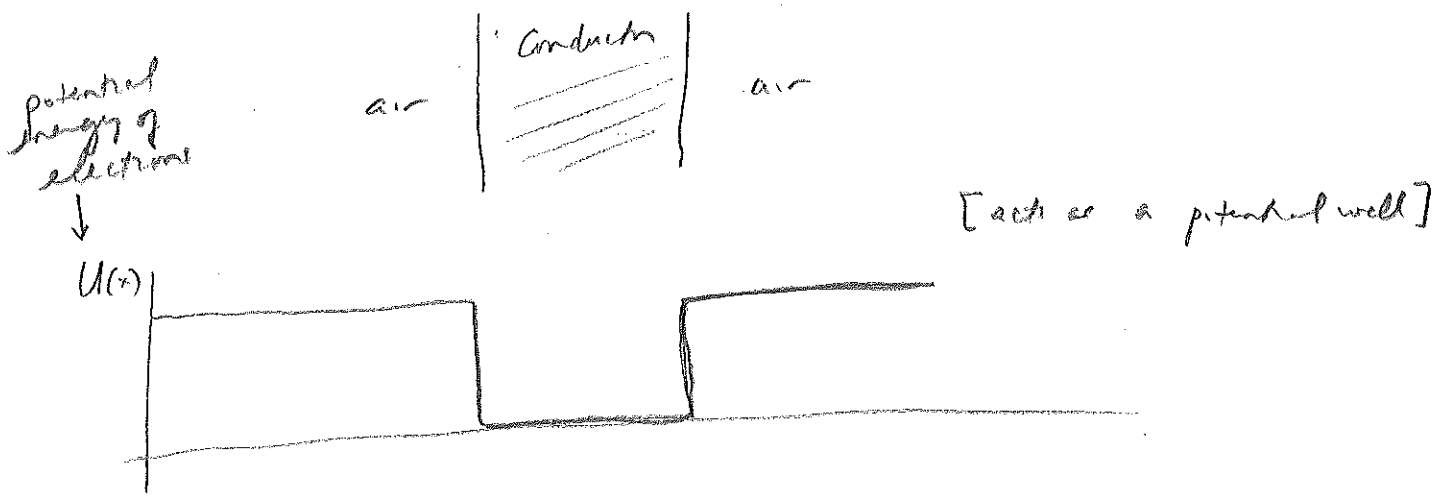
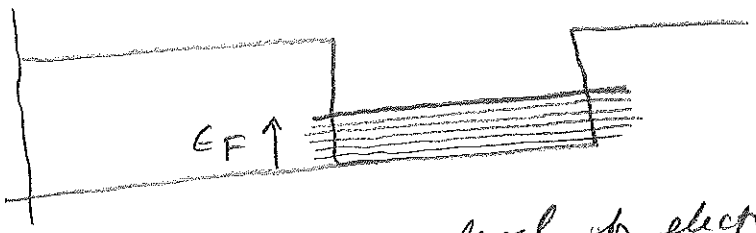
Quantum nature of light: photo electric effect

[Recall: a conductor, e.g. block of metal, contains sea of conduction electrons, that move more-or-less freely through the material.
Responsible for electrical conductivity
Impurities or thermal motion introduce some resistance.
Though electrons move freely through the metal, they are confined]



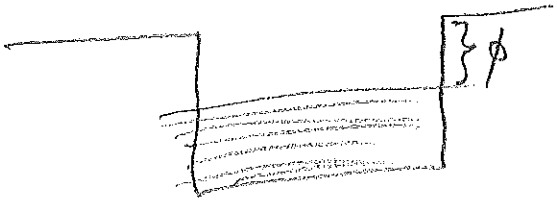
[Electrons have various energy levels inside the metal (quantum mech.)
They also obey Pauli exclusion, so diff. electrons populate diff levels]



The highest energy level for electrons is called the Fermi energy ϵ_F.

Outside the metal is a forbidden region unless additional energy is supplied.

The minimum amt of energy required to liberate an electron is called the work function ϕ of the metal



	ϕ
Na	2.3 eV
Al	4.1 eV
Cu	4.7 eV
Pt	6.3 eV

[Similar to ionization energy for an atom]

How is this energy supplied?

- thermionic emission [heat the metal]
- cold emission [large voltage]
- photo-electric effect [shine light on metal]

When light strikes the surface, electrons can be ejected from the metal, but only if the frequency of light exceeds some critical frequency f_0.

The # of electrons ejected is proportional to the intensity of the light. $I = \frac{1}{2}\epsilon_0 c|A|^2$

[The laddie property makes sense because intensity is the energy carried, so more energy $\Rightarrow$ more electrons if each requires $\sim \phi$. But I does not depend on f.]

Max Planck (1900)

The energy of an electromagnetic wave is emitted & absorbed in discrete chunks, or quanta called photons.

The energy of a photon is proportional to its frequency

$$E = hf$$

h = Planck's constant

$= 6.625 \times 10^{-34}\ J \cdot s$

$= 4.14 \times 10^{-15}\ eV \cdot s$

Since $f = \frac{c}{\lambda} \Rightarrow E = \frac{hc}{\lambda}$

$hc = 1.24 \times 10^{-6}\ m \cdot eV$

$= (1240\ nm) \cdot eV$

e.g. yellow $\lambda \sim 600\ nm \Rightarrow E_{yellow} \sim 2\ eV$

violet $\lambda \sim 400\ nm \Rightarrow E_{violet} \sim 3\ eV$

Total energy of a light wave = (# of photons)(energy per photon)


FoxTrot
by Bill Amend
DO YOU SELL ULTRAVIOLET BULL?
EXCUSE ME?
WHAT ABOUT REGULAR VIOLET BULL?
NO.
BLUE BULL?
NO.
GREEN BULL?
NO.
YELLOW BULL?
NO.
ORANGE BULL?
NO.
RATS. OK, I'LL TAKE A RED BULL.
I WAS HOPING FOR SOMETHING A LITTLE HIGHER-ENERGY.
AT LEAST IT ISN'T INFRARED BULL.
www.foxtrot.com
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[Photo of image of person

As reduce intensity, image becomes dimmer.

Intensity is proportional to # of photons.

Eventually only a small # of photons.]

[Photo of 2 slit experiment]

Photons are not ordinary particles

more likely to end up some places than others.

due to interference.]

Light behaves as a particle when emitted + absorbed,

but as a wave when travelling from source to screen

Wave-particle duality

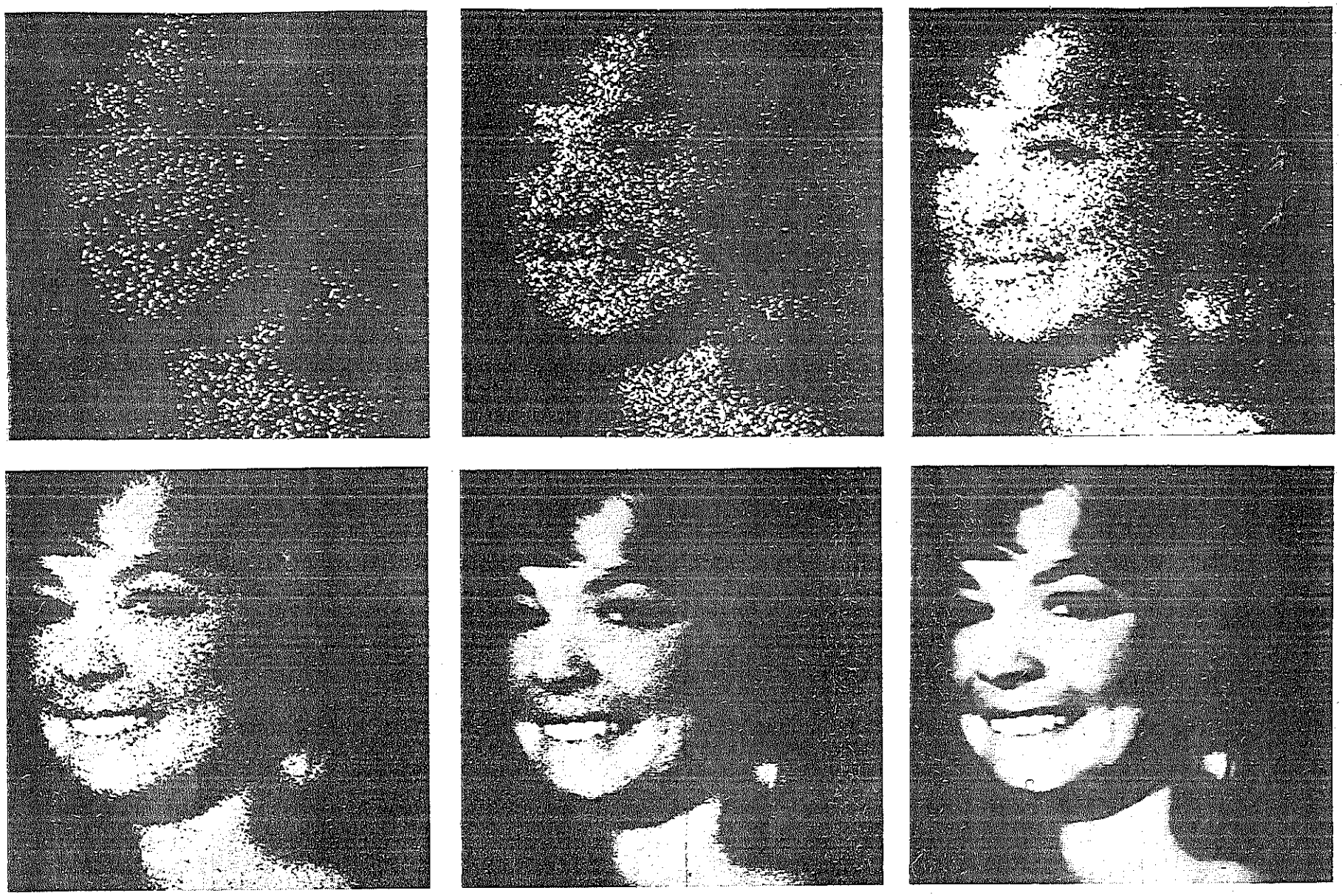
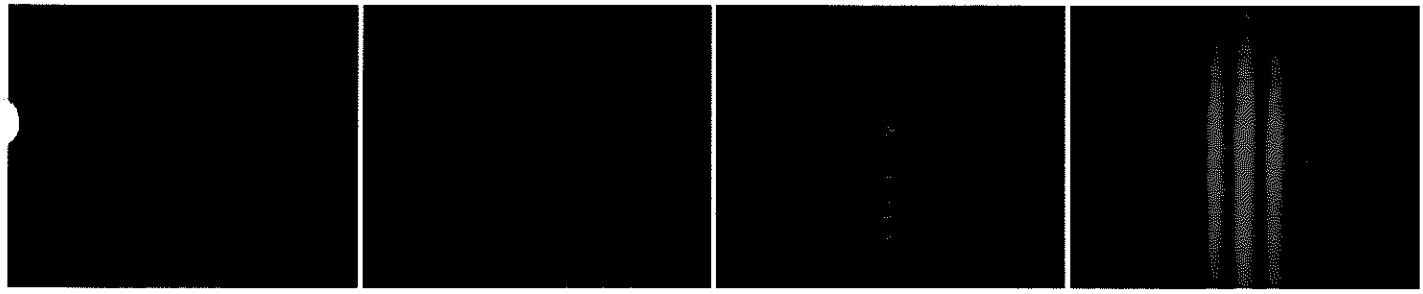
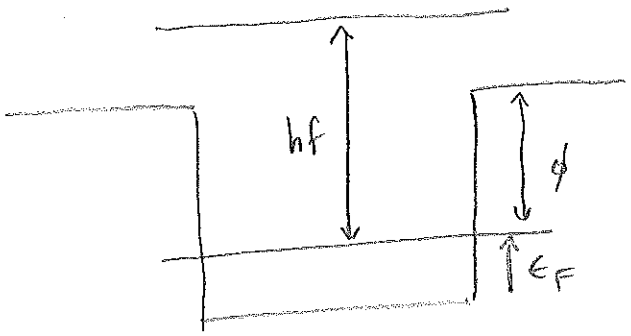


Fig. 1.9 These photos, which were made using electronic amplification techniques, are a compelling illustration of the granularity displayed by light in its interaction with matter. Under exceedingly faint illumination the pattern (each spot corresponding to one photon) seems almost random, but as the light level increases the quantal character of the process gradually becomes obscured. (See *Advances in Biological and Medical Physics* V, 1957, 211–242.) Courtesy Radio Corporation of America.



W-p-dualay-light.jpg in public_html/104scans

Photoelectric effect: a photon striking a metal surface imparts energy hf.



If $hf > \phi$, then electron can leave the surface.

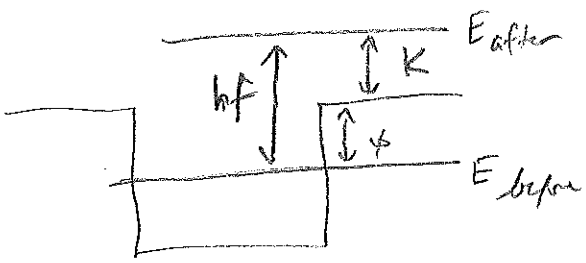
The critical frequency f_0 is the minimum frequency that can liberate an electron

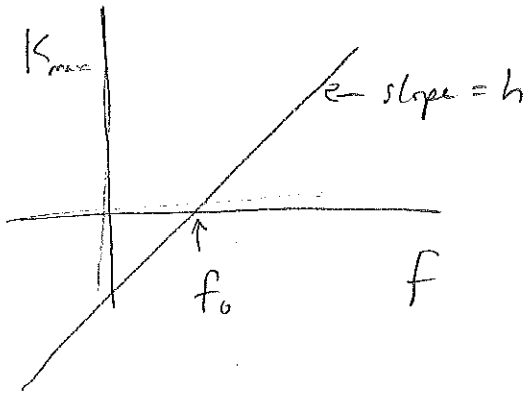
$$hf_0 = \phi$$
$$f_0 = \frac{\phi}{h}$$
$$\lambda_0 = \frac{c}{f_0} = \frac{hc}{\phi}$$

Na: $\phi = 2.3 \Rightarrow \lambda_0 = 540$ nm (green)

[will violet light work?]

If $f > f_0$, the ejected electron will have kinetic energy $K_{max} = hf - \phi$





# of electrons emitted is proportional to the # of photons absorbed which is proportional to the intensity

(physics jeopardy)