Review of Elementary Quantum Physics

Plank's Radiation Law

- Max Planck (Oct 1900) found formula that reproduced the experimental results

$$\rho(\nu,T) = \frac{8\pi\nu^2}{c^3} < E_{osc} >$$

$$< E_{osc} > = \frac{h\nu}{e^{h\nu/kT} - 1}$$

- derivation from classical thermodynamics, but required assumption that oscillator energies can only take specific values E = 0, hν, 2hν, 3hν, … (using "Boltzmann factor" $W(E) = e^{-E/kT}$)

Consequences of Planck's hypothesis

oscillator energies $E = nh\nu$, $n = 0,1,\ldots;$

$h = 6.626\ 10^{-34}$ Js = $4.13\ 10^{-15}$ eV·s

now called Planck's constant

⇒ oscillator's energy can only change by discrete amounts, absorb or emit energy in small packets – "quanta";

$E_{quantum} = h\nu$

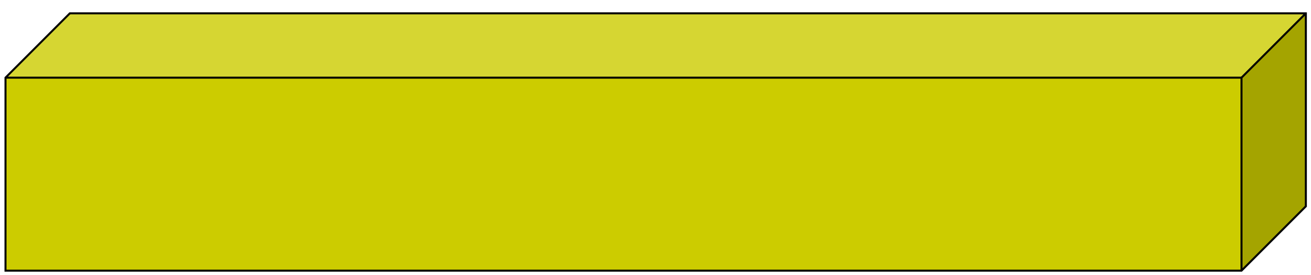
average energy of oscillator

$\langle E_{osc} \rangle = h\nu/(e^x - 1)$ with $x = h\nu/kT$;

for low frequencies get classical result

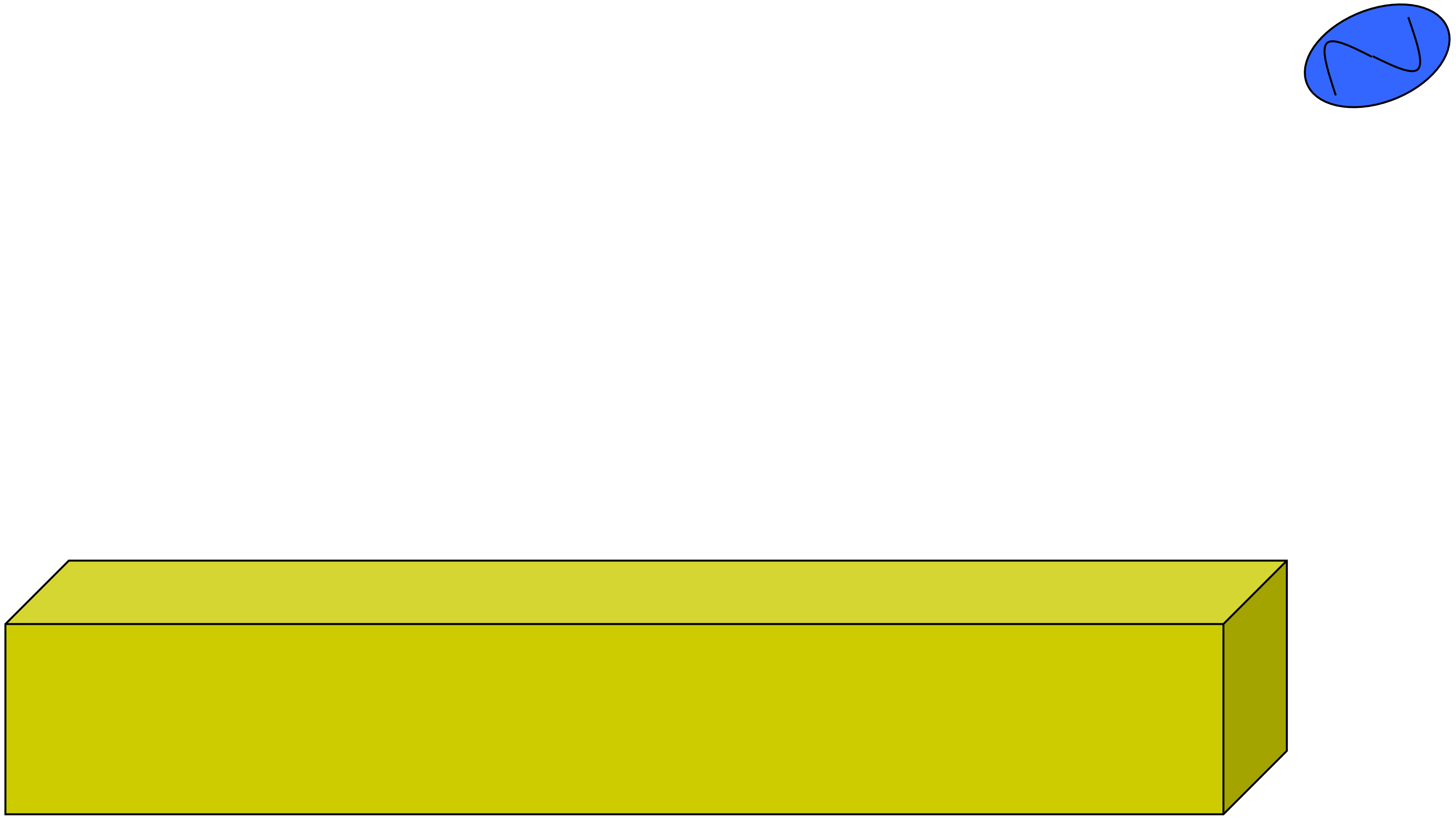
$\langle E_{osc} \rangle = kT$, $k = 1.38 \cdot 10^{-23}$ J·K^{-1}

Photoelectric Effect



Metal Foil

Photoelectric Effect



Metal Foil

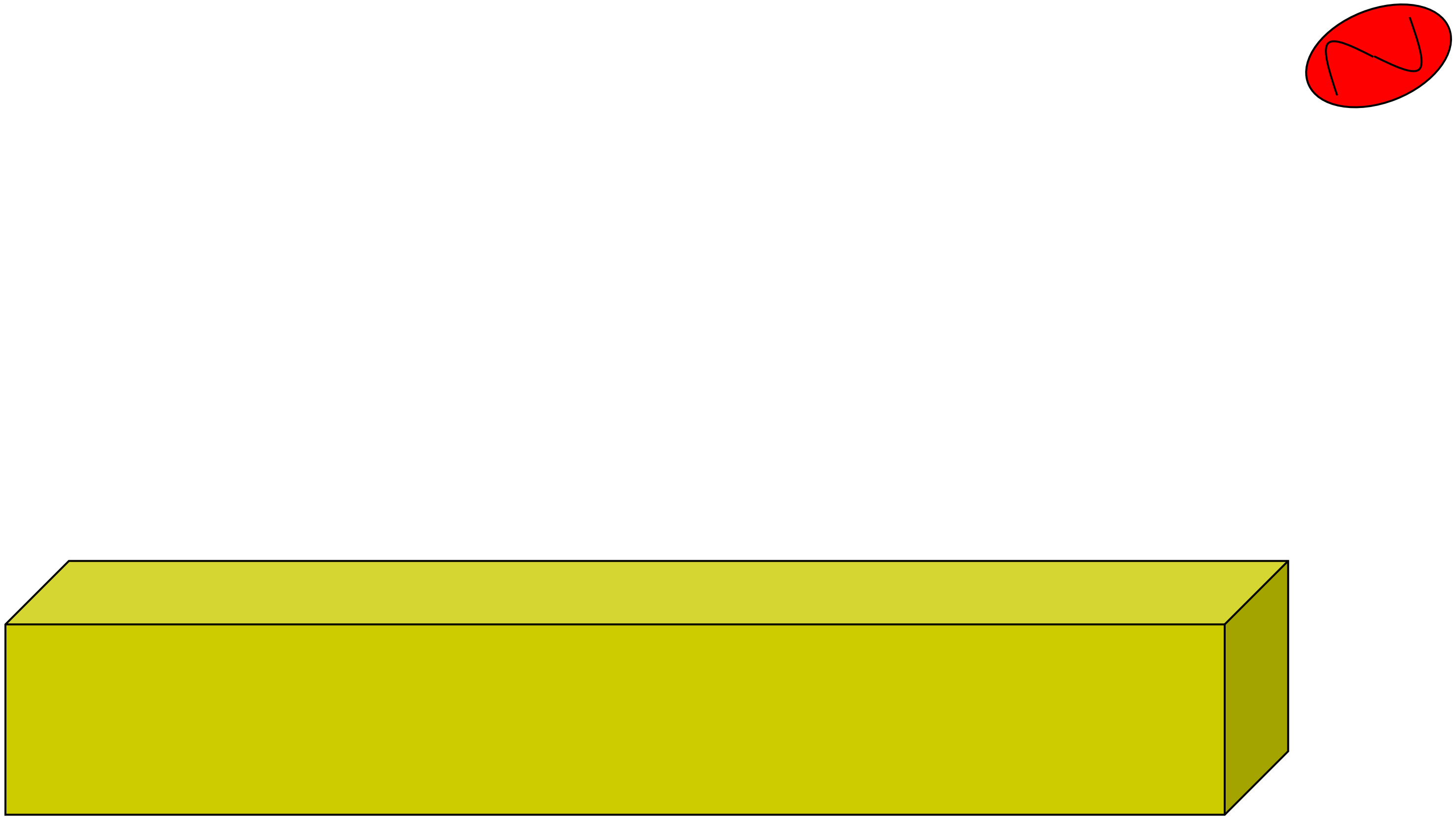
Photoelectric Effect

- As blue light strikes the metal foil, the foil emits electrons.

Photoelectric Effect

- As blue light strikes the metal foil, the foil emits electrons.

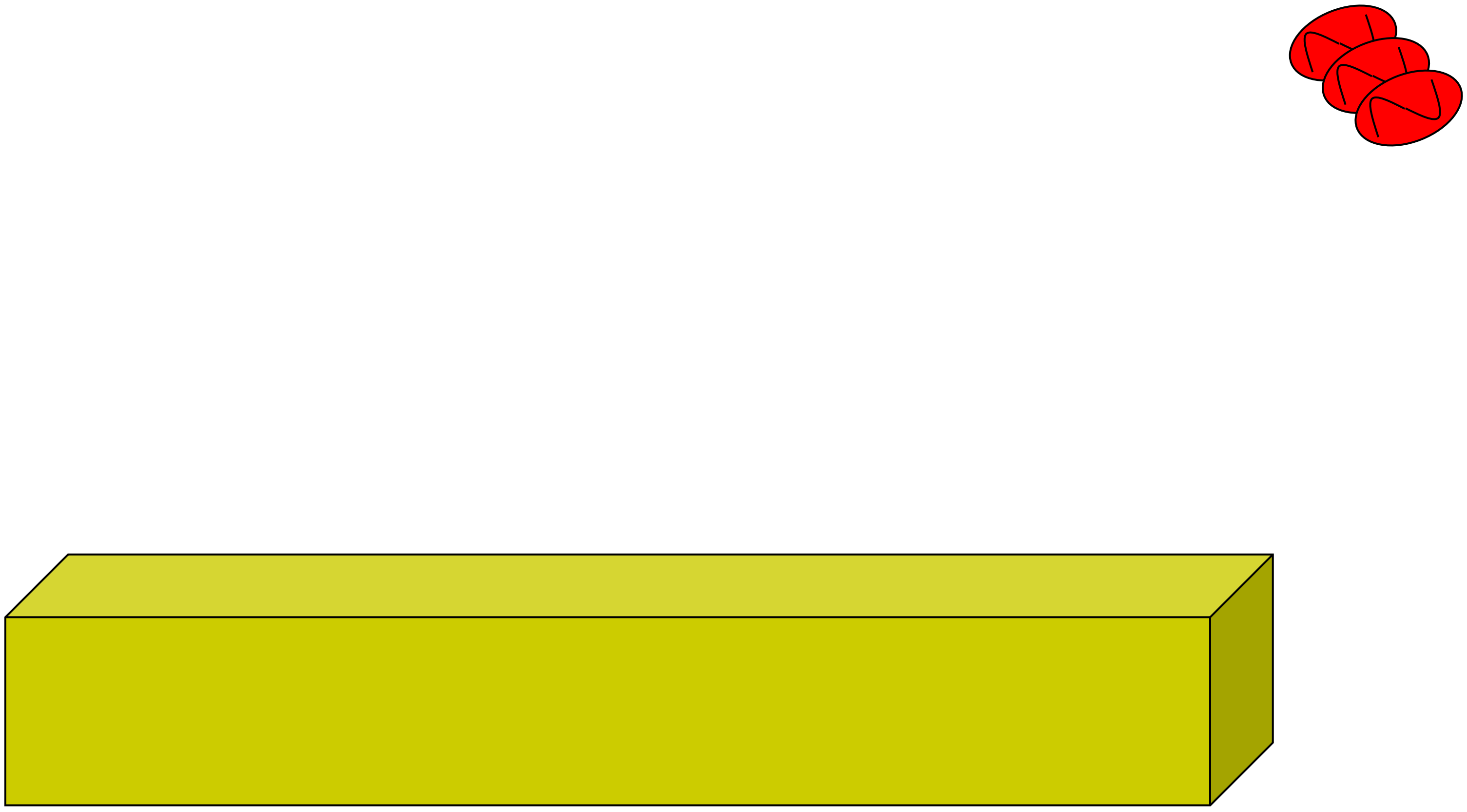
Photoelectric Effect



Photoelectric Effect

- When red light hits the metal foil, the foil does not emit electrons.
- Blue light has more energy than red light.
- How could we get more energy into the red light?
- Try increasing the brightness.

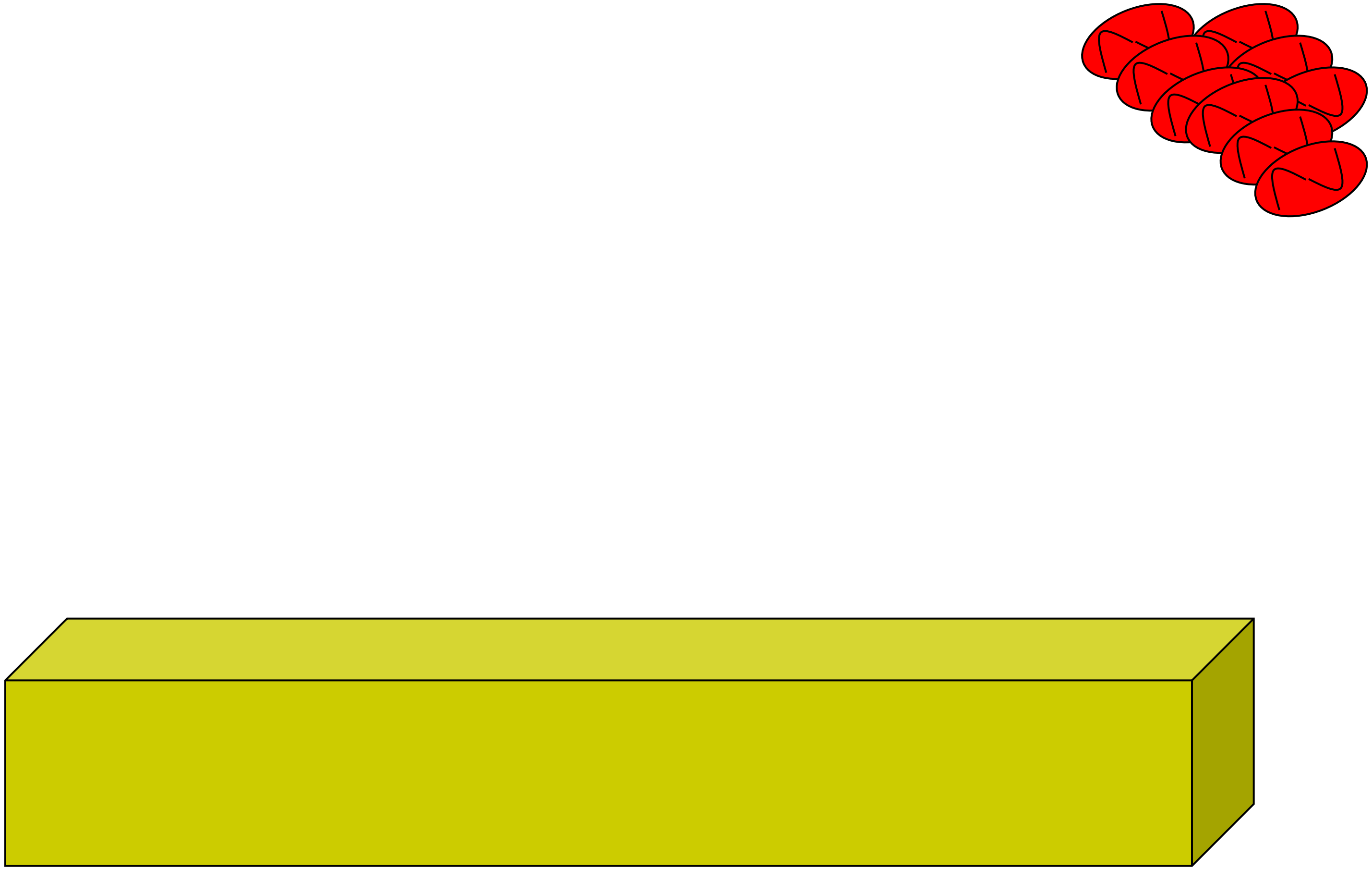
Photoelectric Effect



Photoelectric Effect

- Well, that didn't work!
- Maybe its still not bright enough.

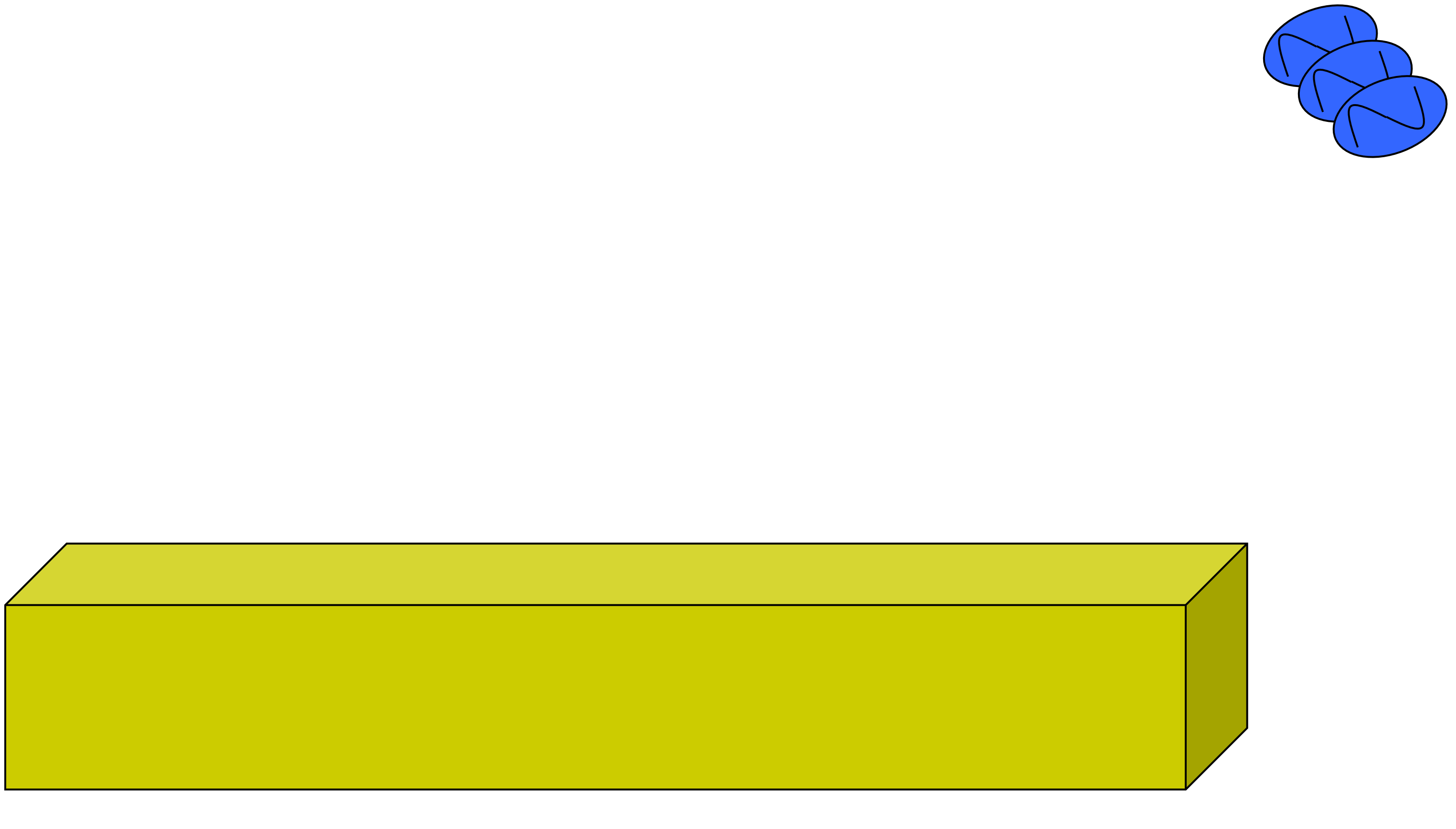
Photoelectric Effect



Photoelectric Effect

- Still not working.
- What happens with brighter blue light?

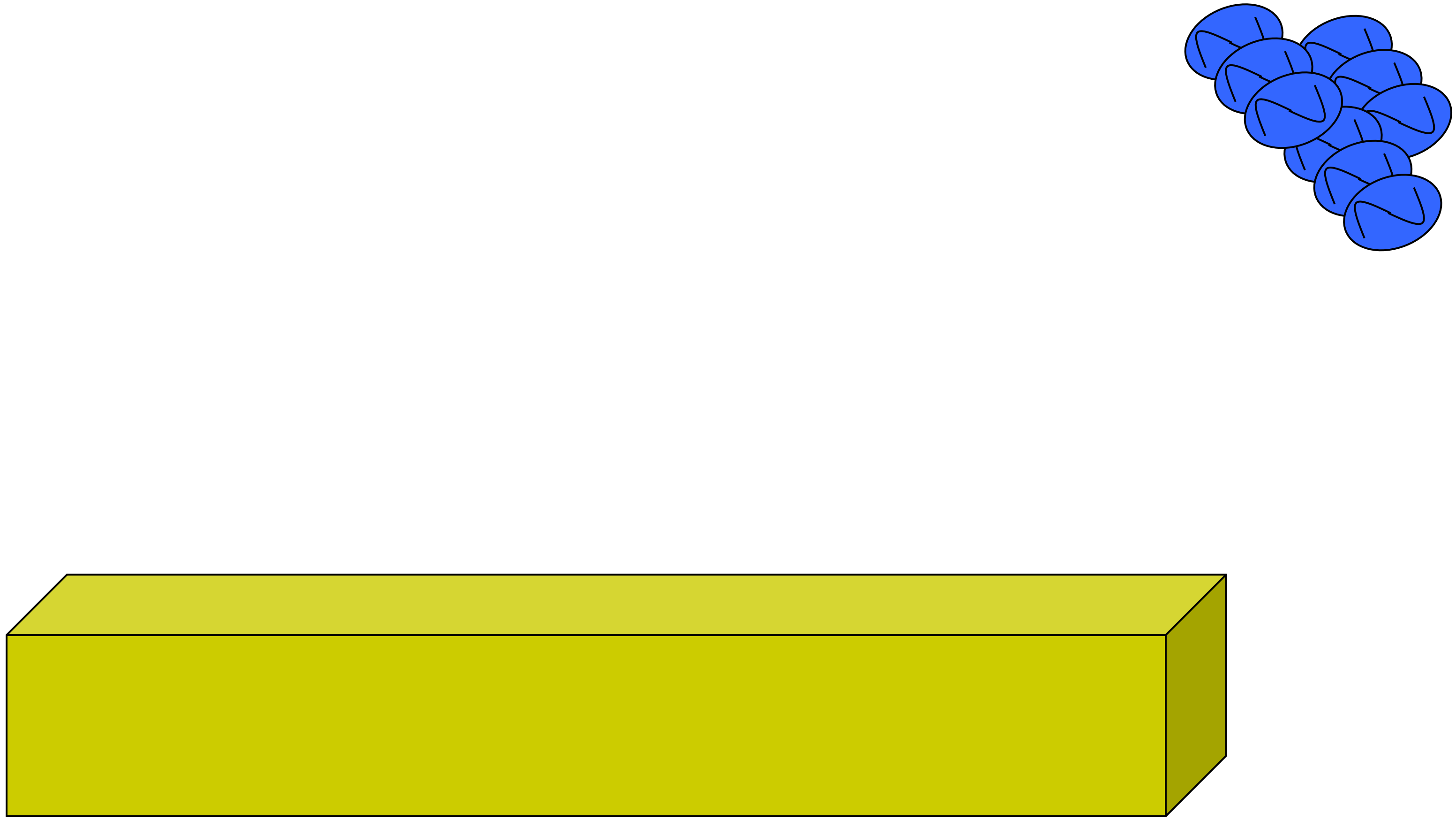
Photoelectric Effect



Photoelectric Effect

- More blue light means more electrons emitted, but that doesn’t work with red.

Photoelectric Effect



Photoelectric Effect

- Wave theory cannot explain these phenomena, as the energy depends on the intensity (brightness)
- According to wave theory bright red light should work!

►***<u>BUT IT DOESN'T!</u>***

Photoelectric Effect

- Einstein said that light travels in tiny packets called ***quanta.***
- The energy of each quanta is given by its frequency

frequency

$$E = h\nu$$

Energy

Planck's constant

Photoelectric Effect

- Each metal has a minimum energy needed for an electron to be emitted.
- This is known as the ***work function, W.***
- So, for an electron to be emitted, the energy of the photon, *hv*, must be greater than the work function, *W*.
- The excess energy is the *kinetic energy, E* of the emitted electron.

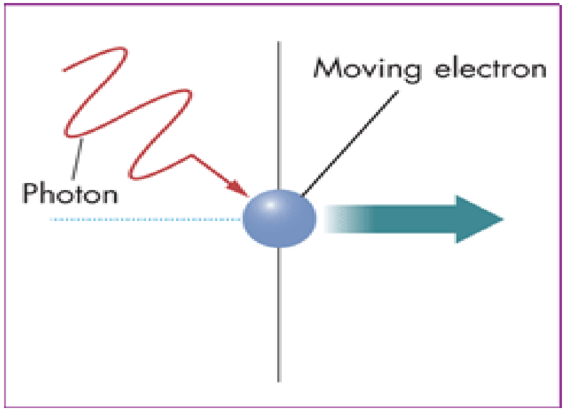
Photoelectric Effect

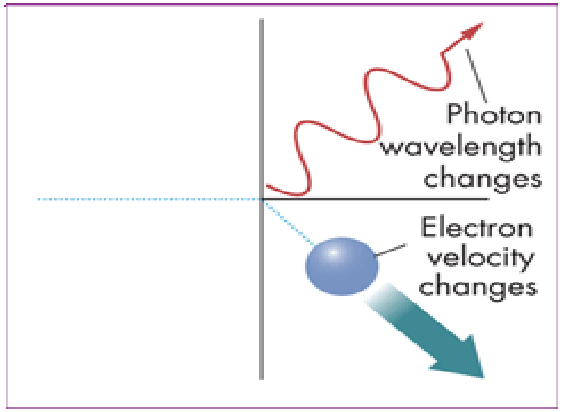
EINSTEIN'S PHOTOELECTRIC EQUATION:-

$$E = h\nu - W$$

The Heisenberg Uncertainty Principle

Before collision: A photon strikes an electron during an attempt to observe the electron's position.





- **After collision:** The impact changes the electron's momentum, making it uncertain.

The Heisenberg Uncertainty Principle

- If we want accuracy in position, we must use short wavelength photons because the best resolution we can get is about the wavelength of the radiation used. Short wavelength radiation implies high frequency, high energy photons. When these collide with the electrons, they transfer more momentum to the target. If we use longer wavelength, i.e less energetic photons, we compromise resolution and position.

The Heisenberg Uncertainty Principle

- Symbolically $\Delta x \approx \lambda$
- $\Delta\ p \approx h/\lambda$
- $\Delta\ p\lambda \approx h$
- $(\Delta p)(\Delta x) \approx h$
- $(\Delta p)(\Delta x) \geq h/2\pi \geq \hbar$

The Heisenberg Uncertainty Principle

- The uncertainty principle can also relate energy and time as follows
- $\Delta t \approx \lambda/c$
- $\Delta E \approx hc/\lambda$
- $(\Delta E)(\Delta t) \approx h$
- $(\Delta E)(\Delta t) \geq h/2\pi \geq \hbar$