

1. Quantum Physics - beginning history

Quantum Physics - beginning history

- End of 19th Century - puzzles (anomalies)
 - Atomic spectra - discrete with regularities
 - X-ray discovery
 - Blackbody radiation
 - Photoelectric effect **All about nature of light**
- Early 20th Century discoveries - Atoms, nuclei, molecules, states of matter
 - Radioactivity and nuclear transmutation
 - electron and atoms

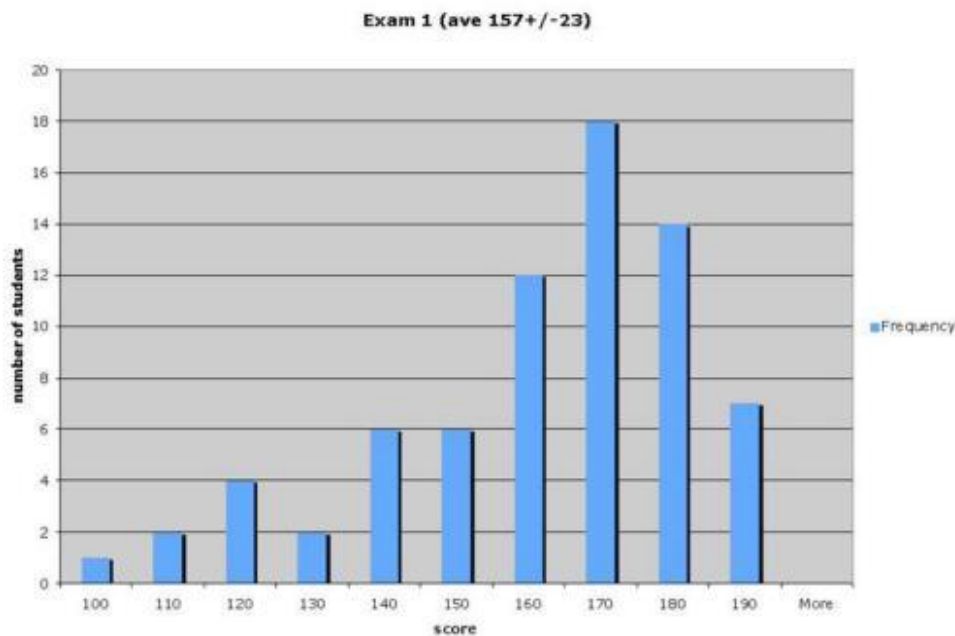
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2. Lecture 12: Early Quantum Physics: Slide 2



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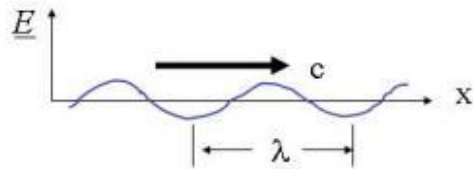
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3. Properties of EM waves

Properties of EM waves



- λ is wavelength
- f is frequency or rate at which cycles pass a fixed point
- $c = \lambda f$ for any wave (travelling plane wave)
- Enormous spectrum of possibilities -> radio, radar, X-rays, ...

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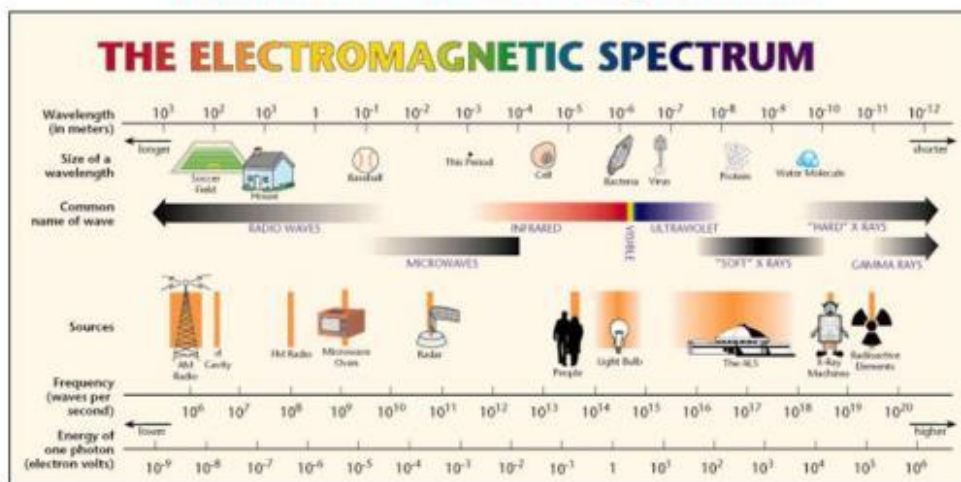
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4. Maxwell EM wave spectrum

Maxwell EM wave spectrum



<http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html>

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5. Blackbody radiation

Blackbody radiation

- Heated objects radiate EM (and absorb)
 - Sun & stars (earth absorbs, reflects & re-radiates)
 - Each square centimeter of the solar surface emits as much light as a 6000 Watt lamp. The temperature of the photosphere is about 5800 K.
 - Solar energy is created deep within the core of the Sun. The core temperature is 15,000,000° C and pressure is 340 billion times Earth's air pressure at sea level, both so intense that nuclear fusion takes place.
- EM spectrum depends on Temperature(K)
- Ideal radiator = Blackbody (also ideal absorber)
- Intensity $\sim R(\lambda, T)$ (Universal function)
 - I(Intensity) is power per unit area (W/m^2)
- Total (all λ) $I \sim T^4$ Stefan's Law (big effect!)
- Peak I at $\lambda \sim 1/T$ Wien's Law

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6. Using Bb radiation proportionalities

Using Bb radiation proportionalities

- Total (all λ) $I \sim T^4$ Stefan's Law (big effect!)
 - Intensity at sun's surface vs. I at earth temp
$$\frac{I_{\text{sun}}}{I_{\text{earth}}} \approx (5800K)^4 / (300K)^4 \approx (19)^4 = 1.3 \times 10^5$$
or $I_{\text{earth}} \approx 7.7 \times 10^{-6} I_{\text{sun}}$
- Peak I at $\lambda \sim 1/T$ Wien's Law
 - Wavelength λ at peak I on sun vs. λ at peak on earth
$$\lambda_{\text{earth}} / \lambda_{\text{sun}} \approx (5800K) / (300K) \approx 19$$
visible light for λ from 400 nm to 700 nm
so for $\lambda_{\text{sun}} \approx 600\text{nm}$ get $\lambda_{\text{earth}} \approx 12,000\text{nm} \approx 12 \mu\text{m}$
This is infrared (see chart)

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7. Blackbody spectrum

Blackbody spectrum

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8. Quantum physics's first problem

Quantum physics' first problem

- Blackbody radiation - intensity vs. frequency
- Problems in interpretation - UV Catastrophe
- Planck: oscillating molecules in walls emit & absorb EM radiation in discrete amounts only
- $E=hf$ with $h=6.6 \times 10^{-34}$ Joule sec (not the Classical $E \sim (f \times \text{Electric force or wave amplitude})^2$)
 - h is very small!
- What is EM radiation? Waves or Particles?
 - Interference or collisions?

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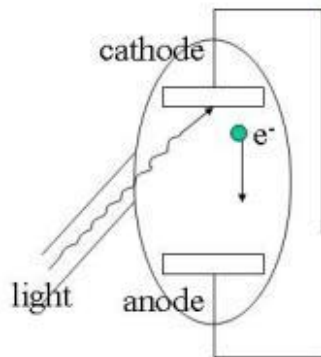
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9. Photoelectric effect (Hertz 1887)

Photoelectric effect (Hertz 1887)



- Light on metal “boils off” electrons - makes a current (amps)
- Fix Voltage V (or electric force) across tube
- Measure current vs. f and light intensity I
- Vary V

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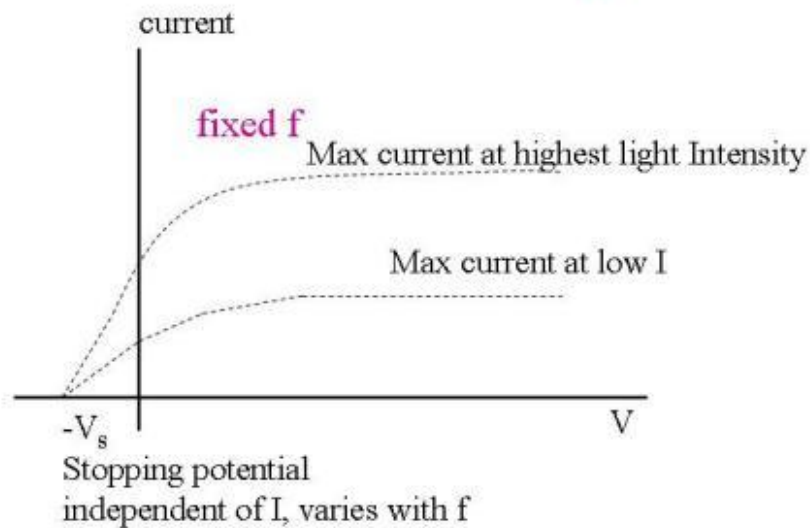
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10. Current vs. Voltage

Current vs. Voltage



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11. Interpretation of photoelectric effect

Interpretation of photoelectric effect

- Classical - EM wave imparts energy to electrons
 - Higher I \rightarrow higher current, V_s depends on I
 - **Not what data show**
 - Current saturates for given f and I with V
 - V_s depends on f

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12. Photoelectric effect and photons

Photoelectric effect and photons

- Einstein explains effect: Planck's quantum becomes $E=hf$ packet of EM energy or **photon** (γ)
 - As example consider visible light, for $\lambda \approx 5 \times 10^{-7} \text{ m}$
have $f=c/\lambda = 3 \times 10^8 \text{ m/s} / 5 \times 10^{-7} \text{ m} = 6 \times 10^{14} \text{ sec}^{-1}$
Then $E(\text{photon}) = hf = 6.6 \times 10^{-34} \text{ J}\cdot\text{s} \cdot 6 \times 10^{14} \text{ s}^{-1}$
 $= 4 \times 10^{-19} \text{ J} = 2.5 \text{ eV}$
- Why don't we see these photons? Consider an everyday source of light:
- How many γ 's from 40 Watt light bulb? $1\text{W}=1\text{J/sec}$
Take average $\lambda \approx 5 \times 10^{-7} \text{ m}$, so each γ carries $4 \times 10^{-19} \text{ J}$.
Then number of γ 's per second is $40 \text{ J/s} / 4 \times 10^{-19} \text{ J} = 10^{20}/\text{sec}$
- What about light from warm objects in ordinary environment?
measure of thermal energy is kT
where k =Boltzmann's constant, T =temp in Kelvin (=Centigrade+273)
So at $T=290 \text{ K}$ (room temp) thermal energy is
 $1.38 \times 10^{-23} \cdot 290 \approx 4.0 \times 10^{-21} \text{ J} \approx 2.5 \times 10^{-2} \text{ eV}$ corresponds to $\lambda \approx 5 \times 10^{-5} \text{ m}$

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13. Quantum theory of photoelectric effect

Quantum theory of photoelectric effect

- Einstein(1905): Light = photons = quanta
- and $E = hf$ Wave-particle duality
- Photon hits electron in metal giving e^- energy to escape (e^- loses some in getting out)
- Max Kinetic Energy of electron = KE_{\max}
 $= \frac{1}{2} m v_{\max}^2 = eV_s$ (stopping voltage) = hf
- KE_{\max} is independent of Intensity (power/area)
- electrons can not absorb all I, only 1 e^- per 1 γ
- Will need to think of probability for γ s to be emitted or absorbed

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