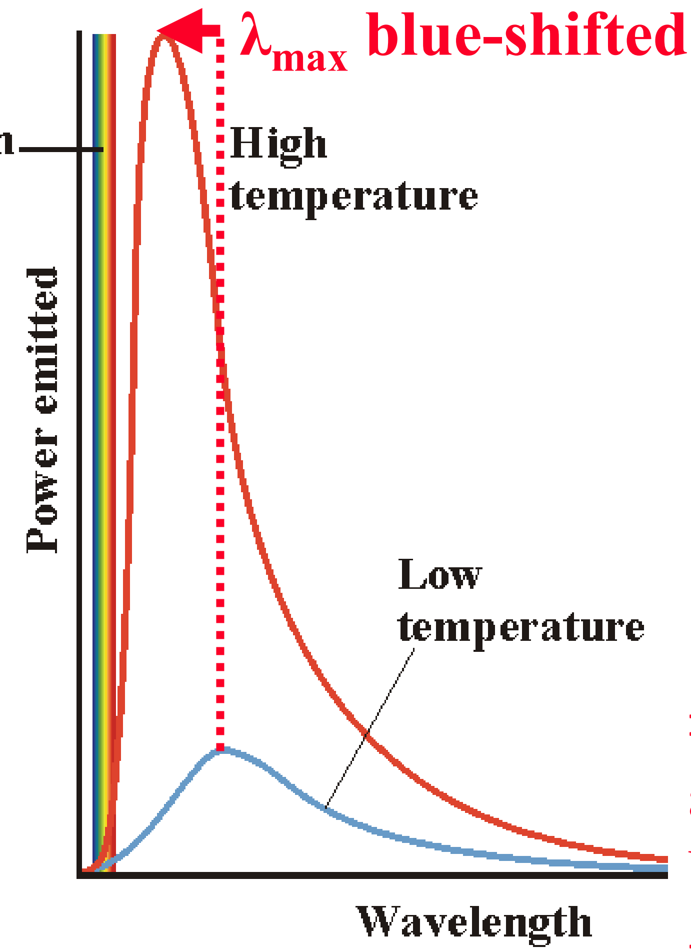
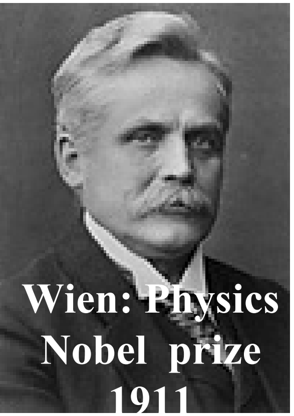
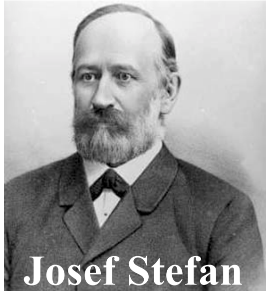
Properties of Black-Body Radiation

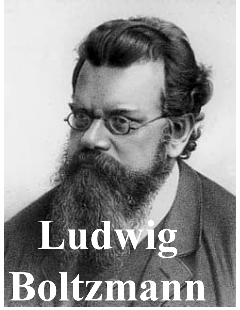
Power density of a black body:

λ_{max} blue-shifted ("white")









Emittance = total power emitted

⇒ Stefan-Boltzmann law:

$$M = aT^4; a = 56.7\, nW\, m^{-2}\, K^{-4}$$

⇒ The higher the temperature of a lamp wire, the more power will be emitted as light!

⇒ Halogen lamps!

Wien's displacement law: $T\lambda_{max} = 2.9\, mm\, K$

⇒ Surface temperature of the sun w/ $\lambda_{max} \approx 490$ nm!

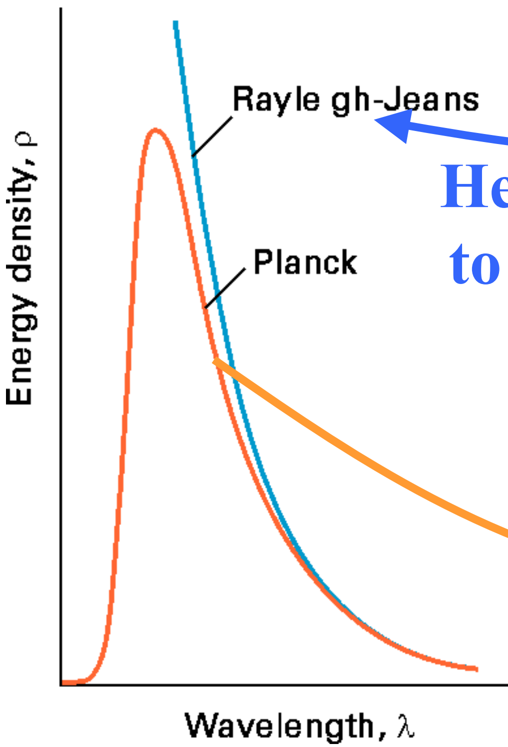
The Problem of Classical Physics

"Electromagnetic radiation are waves in a ubiquitous 'ether'; this ether can oscillate at any frequency"

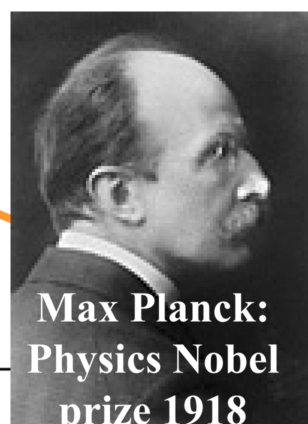
$\Rightarrow$ Rayleigh-Jeans law:

Contribution to the energy density of a black body from radiation in the narrow range λ to $\lambda + \Delta\lambda$: $\rho\,\Delta\lambda$

with $$\rho = \frac{8\pi kT}{\lambda^4}$$

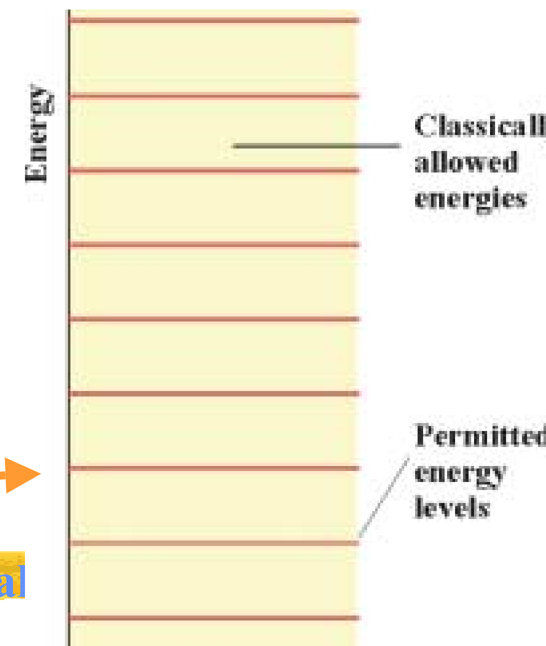


Heating your stove would lead to an ultraviolet catastrophe!



Energy levels are discrete!

Nils Wal



Quantization of Energy Helps Explain Black Body Radiation!

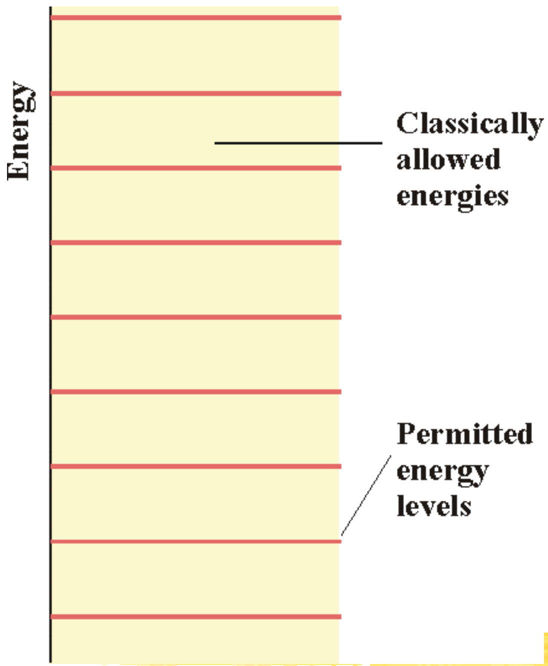
Specifically:

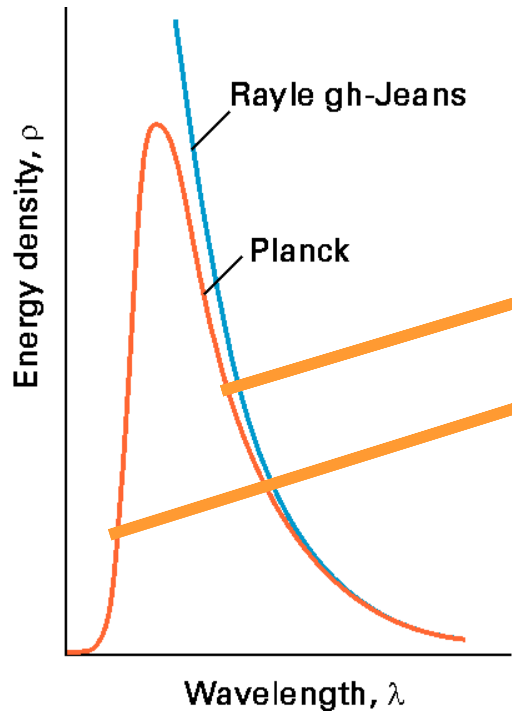
$E = nh\nu$ (quantized)

$h = 6.626 \times 10^{-34}$ Js

(Planck's constant)

$n = 0, 1, 2, \ldots$





Planck distribution:

$$\rho = \frac{8\pi hc}{\lambda^5}\left(\frac{1}{e^{hc/\lambda kT}-1}\right)$$

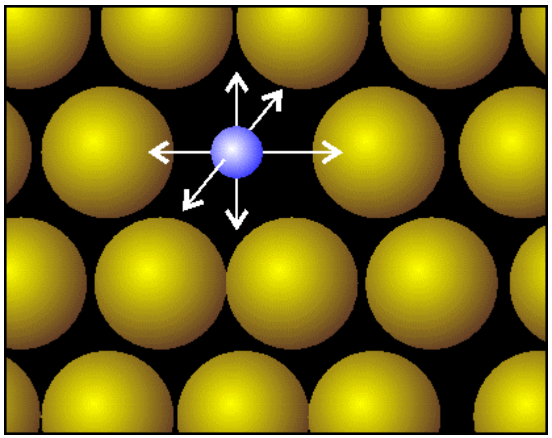
⇒ Eliminates the ultraviolet catastrophe since high-frequency (energy) oscillators are not excited

⇒ Quantitatively accounts for the Stefan-Boltzmann and Wien laws!

Case 2: Quantization of Energy Helps Explain Experimental Heat Capacities!

Your stove top boiler plate has a certain heat capacity: $q = C\Delta T$

Heat capacity = Proportionality constant to describe how much T rises when heat energy q is taken up



Heat = thermal motion of atoms

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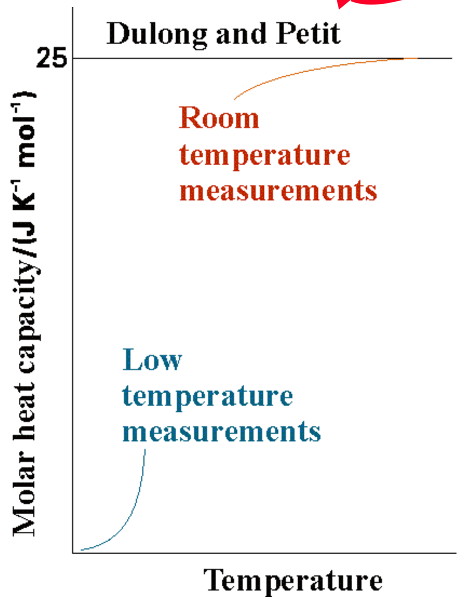
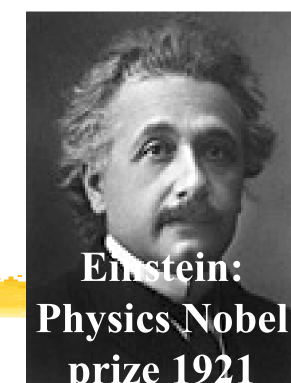
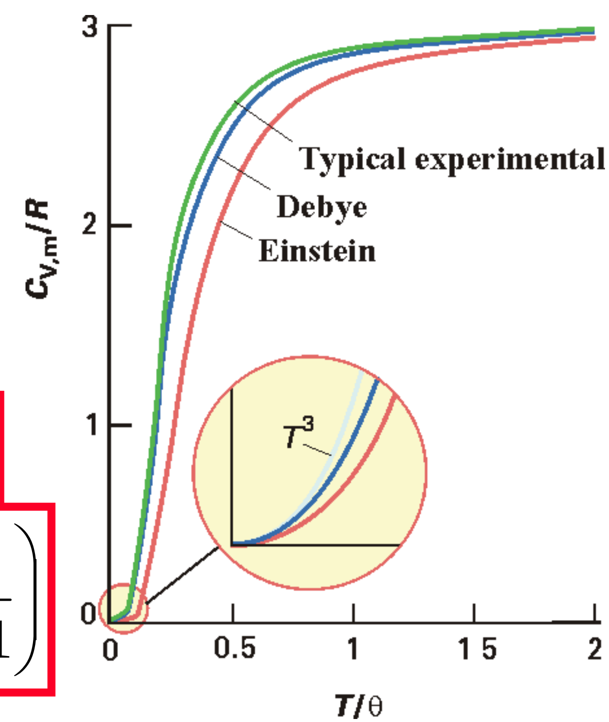
Energy levels are discrete!



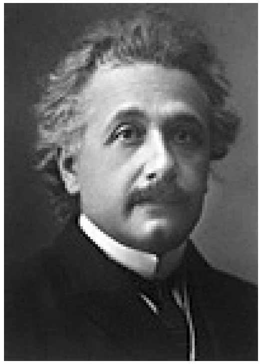


$$C_{v.m} = 3Rf^2$$

$$f = \frac{h\nu}{kT}\left(\frac{e^{h\nu/2kT}}{e^{h\nu/kT} - 1}\right)$$



Case 3: Quantization of Energy Explains the Photoelectric Effect

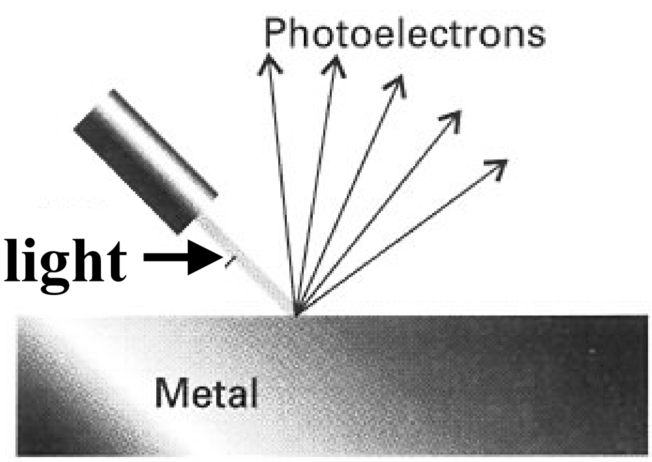


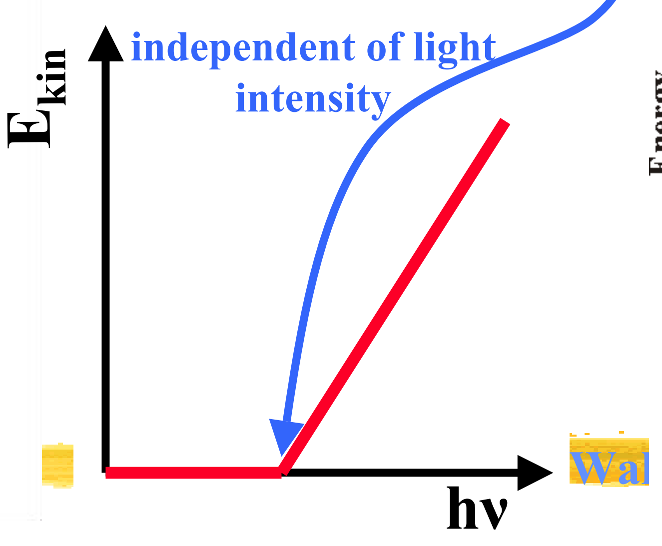
Think it through:

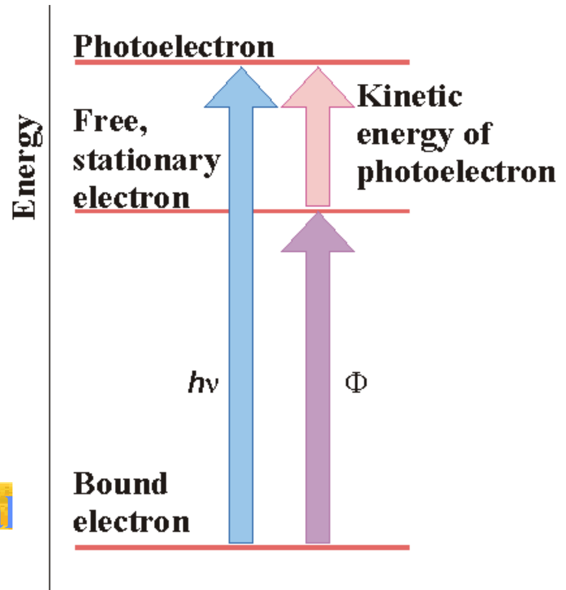
If the energy of electromagnetic radiation is quantized in integers of hν, it is easiest to imagine it as particles or…. photons!

⇒ Intense (high-power) light = NOT larger amplitude radiation (as expected classically), BUT more photons

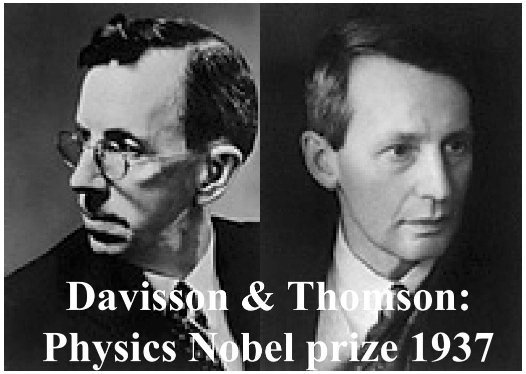
photoelectrons: $E_{kin} = \frac{1}{2} m_e v^2 = h\nu - \Phi$



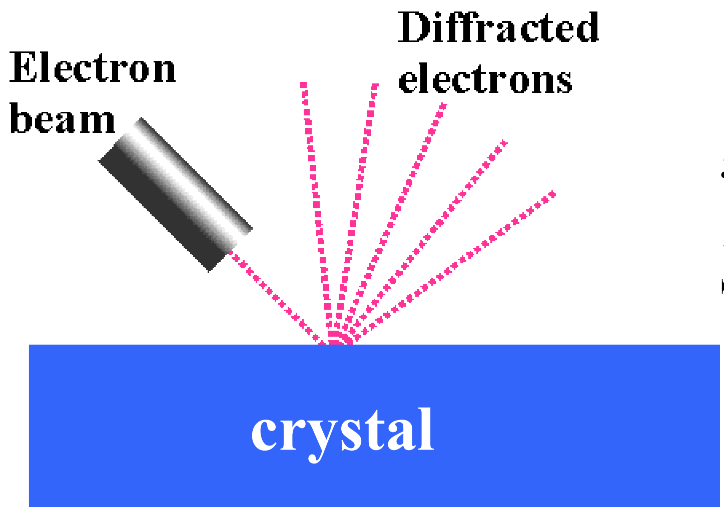




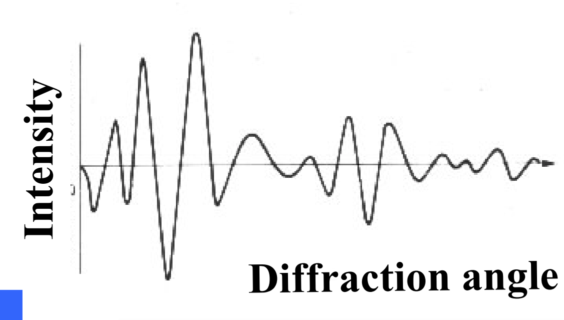
Another surprise: Particles can be diffracted



Davisson & Thomson: Physics Nobel prize 1937



Interference pattern



e^- interference

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Particles can behave wave-like (and waves particle-like)

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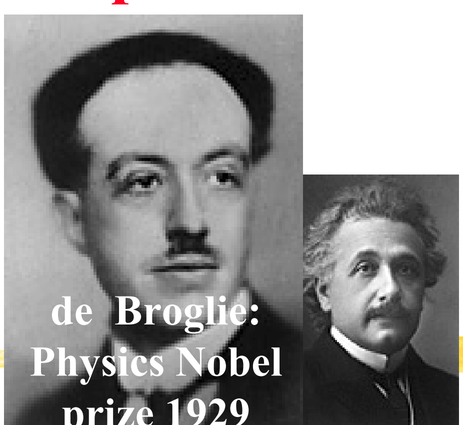
Wave-particle duality!



de Broglie: Physics Nobel prize 1929

Photons: $E = h\nu$

and $E = mc^2$

and $\nu = \dfrac{c}{\lambda}$

and impulse $p = mc$

de Broglie relation:

$$\Rightarrow \quad \lambda = \frac{h}{p}$$