Introduction of quantum history

1859 Gustav Kirchhoff proved a theorem about blackbody radiation. He also proved that the energy emitted E depends only on the temperature T and the frequency v of the emitted energy, i.e.

$$E = J(T,v).$$

1879 Josef Stefan proposed, on experimental grounds, that the total energy emitted per unit time per unit area (R_T) by a black body was proportional to the fourth power of the temperature.

$$R_T = \sigma T^4$$

1900 Planck read his paper, "On the Theory of the Energy Distribution Law of the Normal Spectrum", at the German Physical Society Meeting. He made the unprecedented step of assuming that the total energy is made up of indistinguishable energy elements - quanta of energy, which marks the start of quantum era. Planck won the 1918 Nobel Prize for Physics for this work.

1905 Einstein examined the photoelectric effect. He received the 1921 Nobel Prize for Physics for this work. We will discuss this effect next week.

1913 Niels Bohr wrote a revolutionary paper on the hydrogen atom. He discovered the major laws of the spectral lines. This work earned Bohr the 1922 Nobel Prize for Physics. Arthur Compton derived relativistic kinematics for the scattering of a photon (a light quantum) off an electron at rest in 1923. We will discuss this effect next week.

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1924 A fundamental paper written by Satyendra Nath Bose was rejected by a referee for publication. Bose then sent the manuscript to Einstein who immediately saw the importance of Bose's work and arranged for its publication. Bose proposed different states for the photon. He also proposed that there is no conservation of the number of photons.

1924 The doctoral thesis of Louis de Broglie was presented which extended the particle-wave duality for light to all particles, in particular to electrons. Schrödinger in 1926 published a paper giving his equation for the hydrogen atom and heralded the birth of wave mechanics. Schrödinger introduced operators associated with each dynamical variable.

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1926 Born abandoned the causality of traditional physics. Speaking of collisions Born wrote:

One does not get an answer to the question, What is the state after collision? but only to the question, How probable is a given effect of the collision? From the standpoint of our quantum mechanics, there is no quantity which causally fixes the effect of a collision in an individual event.

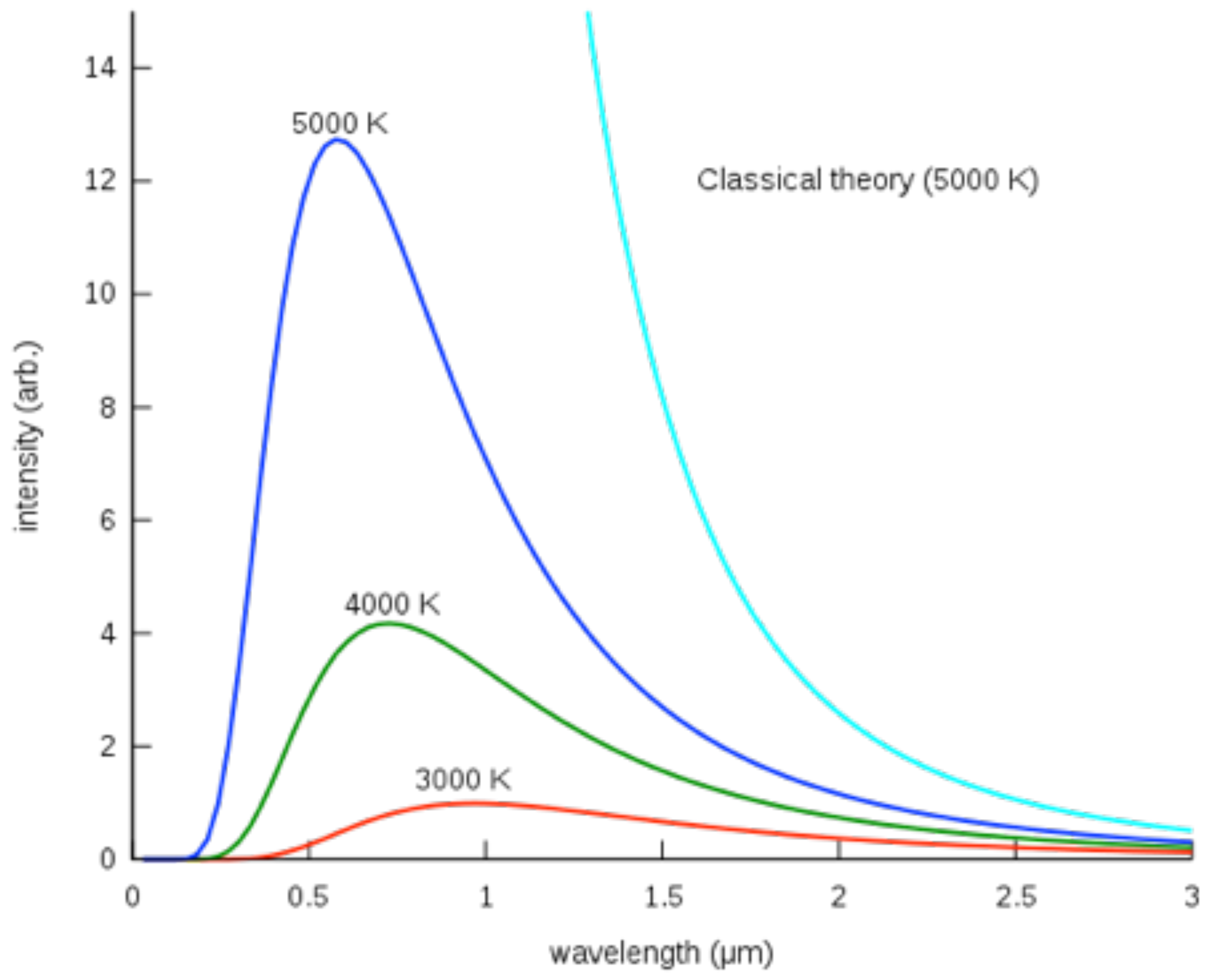
1927 Heisenberg stated his uncertainty principle. It states that the process of measuring the position x of a particle disturbs the particle's momentum p, so that

$\triangle x \, \triangle p \geq h/2\pi$

1928 Dirac gave the first solution of the problem of expressing quantum theory in a form which was invariant under the Lorentz group of transformations of special relativity.

1932 von Neumann put quantum theory on a firm theoretical basis -- the setting of operator algebra.

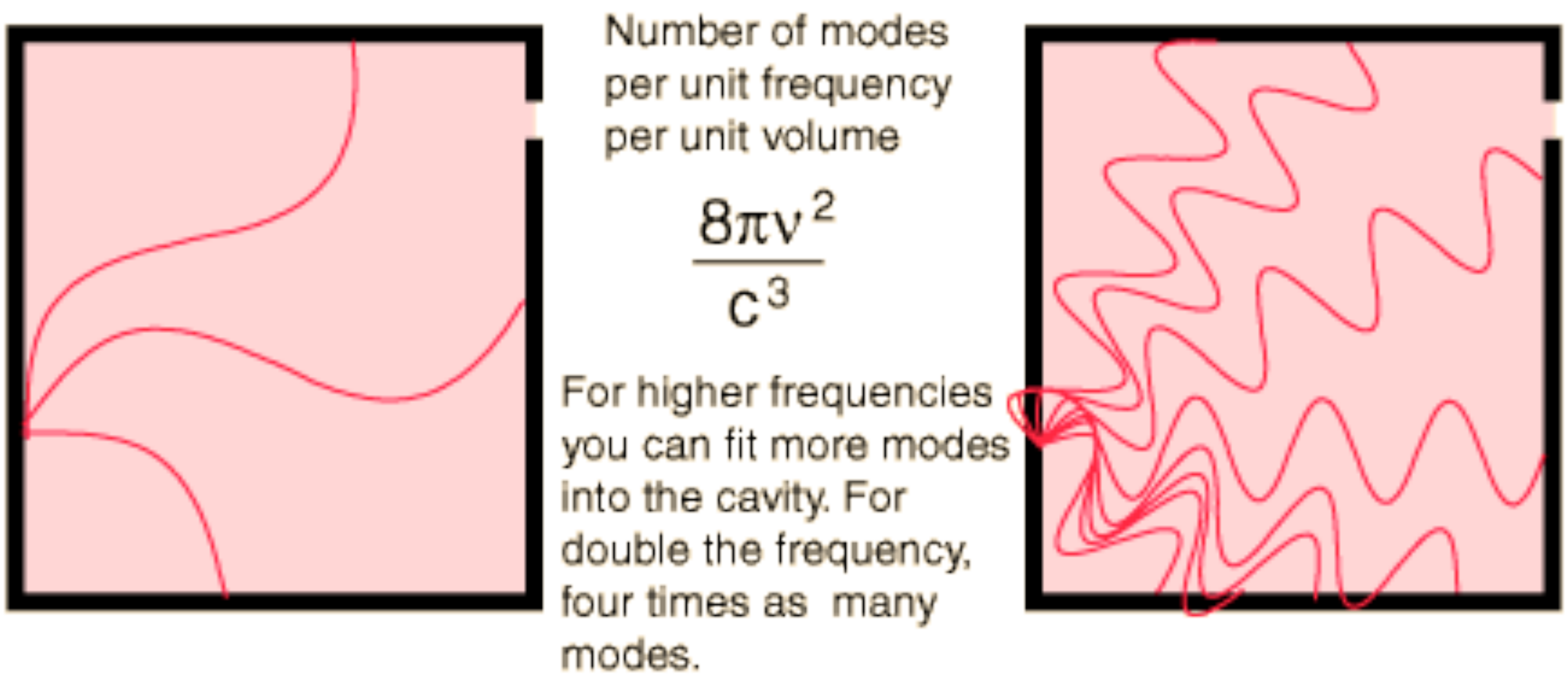
Thermal radiation

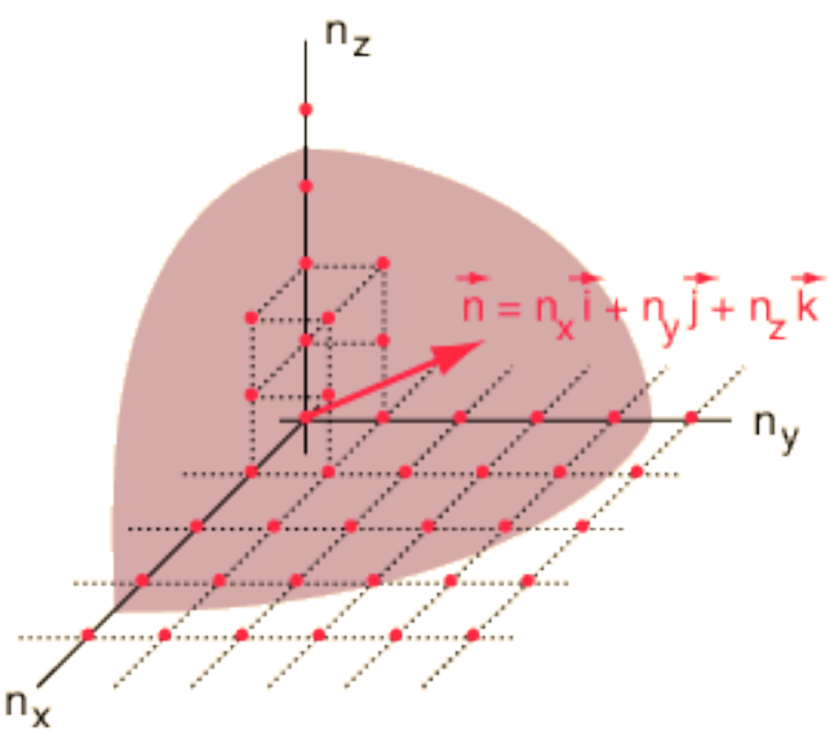


$$\lambda_{max} = b/T$$

$$R_T = \sigma T^4$$

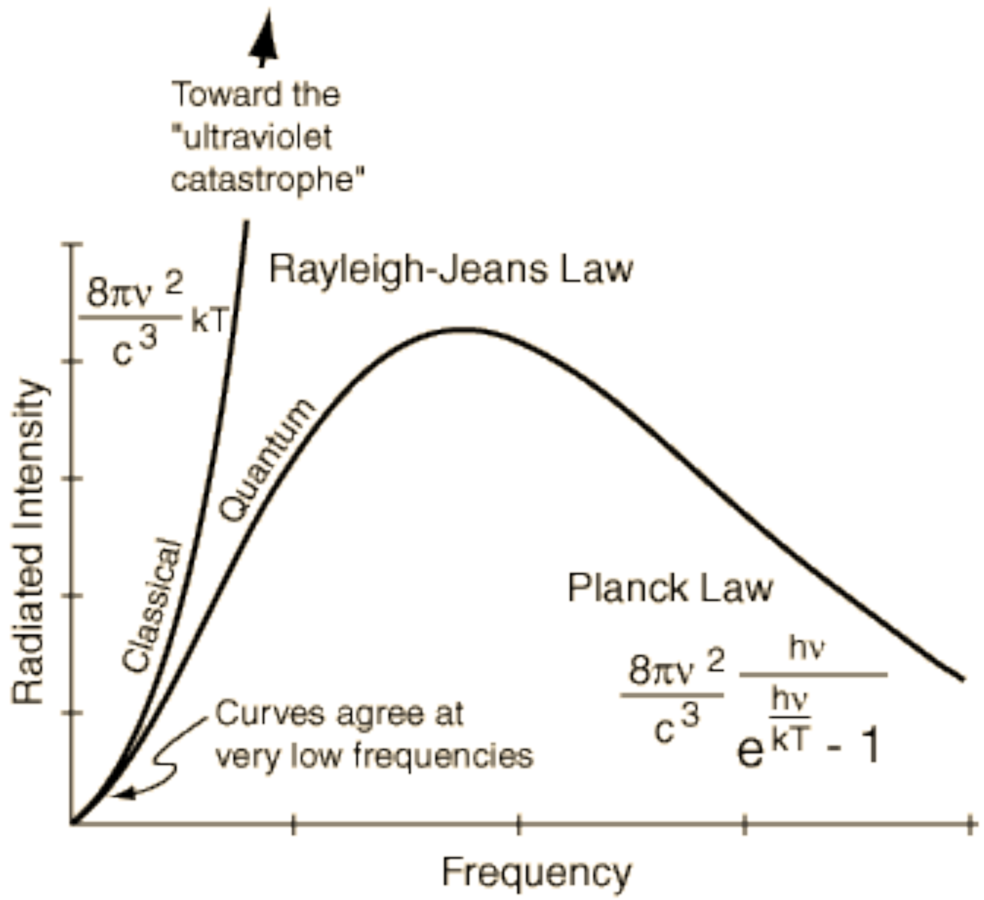
Number of radiation modes in cavity





$$\frac{\text{Number of modes per unit wavelength}}{\text{Cavity volume}} = -\frac{1}{L^3}\frac{dN}{d\lambda} = \frac{8\pi}{\lambda^4}$$

Planck's postulations



$$\langle E \rangle \xrightarrow[\upsilon \to 0]{} kT$$

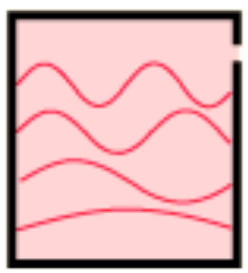
$$\langle E \rangle \xrightarrow[\upsilon \to \infty]{} 0$$

$$\langle E \rangle = \frac{h\upsilon}{e^{h\upsilon/kT} - 1}$$

Energy density of radiation cavity

$E_T(\upsilon)d\upsilon$: Energy per unit volume in the frequency interval υ and $\upsilon + d\upsilon$

Radiation modes in a hot cavity provide a test of quantum theory



	#Modes per unit frequency per unit volume	Probability of occupying modes	Average energy per mode
CLASSICAL	$\frac{8\pi\nu^2}{c^3}$	Equal for all modes	kT
QUANTUM	$\frac{8\pi\nu^2}{c^3}$	Quantized modes: require $h\nu$ energy to excite upper modes, less probable	$\frac{h\nu}{e^{\frac{h\nu}{kT}} - 1}$

Homework #1

Please derive the following eq.

$$\langle E \rangle = \int E p(E) dE \Big/ \int p(E) dE = kT,$$

where $p(E) = exp(-E/kT)/kT$