History overview of quantum theory

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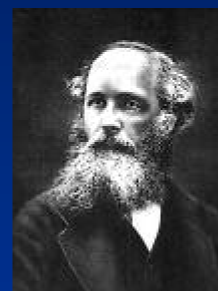
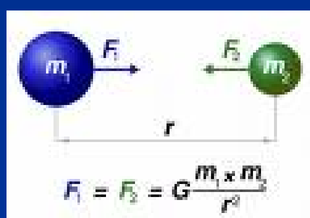
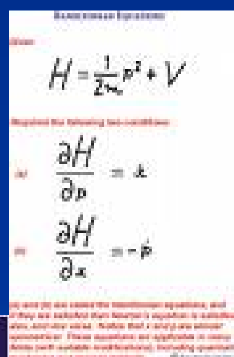
Fall, 2009

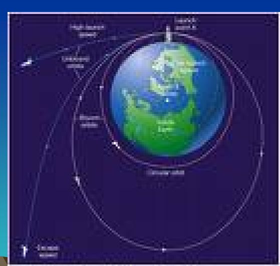
Classical Physics

- Before 1900: Classical physics claimed a full victory

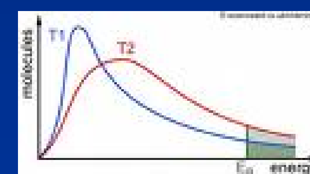








$$\oint \mathbf{E}\cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$
$$\oint \mathbf{B}\cdot d\mathbf{A} = 0$$
$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$
$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$



$$\frac{N_j}{N} = \frac{e^{-\varepsilon_j/kT}}{\sum_i e^{-\varepsilon_i/kT}}$$

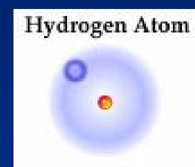
Classical Electrodynamics

Newton Law and Gravity

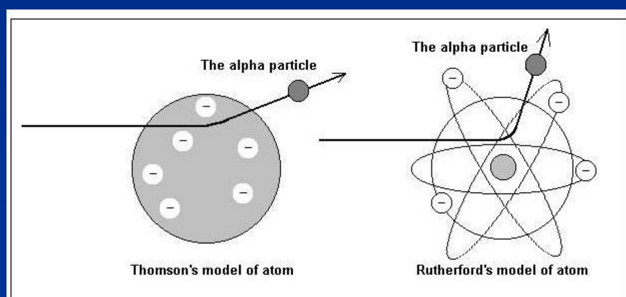
Classical Statistical Physics

Atomic Hypothesis

- Around 1900: The atomic hypothesis became popular
  - 1897: electron was discovered.



  - 1905: Rutherford atomic model 



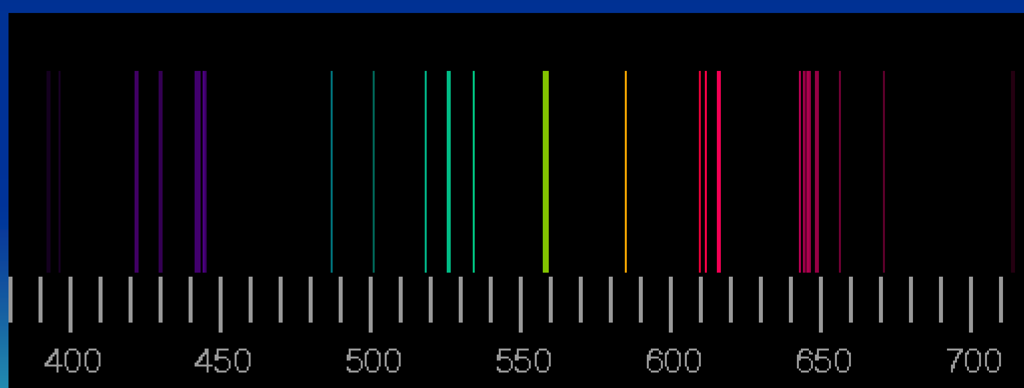
The models of the Thomson's atom and Rutherford's atom; and the expected aberrations of alpha particle in both cases.

- If the model is right, it is the end of classical mechanics.
- How can be an atom stable?
- Energy would be lost by radiation.
- Surrounding Electrons would have collapsed to nuclear.

There must be new physical laws!

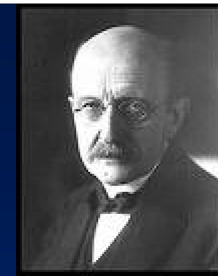
Atomic Hypothesis

- Around 1900: The color of atoms
  - Different atoms glowed in different colors
  - Optical spectrum of atoms: characteristic of the elements
  - Balmer (1885) found an ordering principle in atomic spectra.



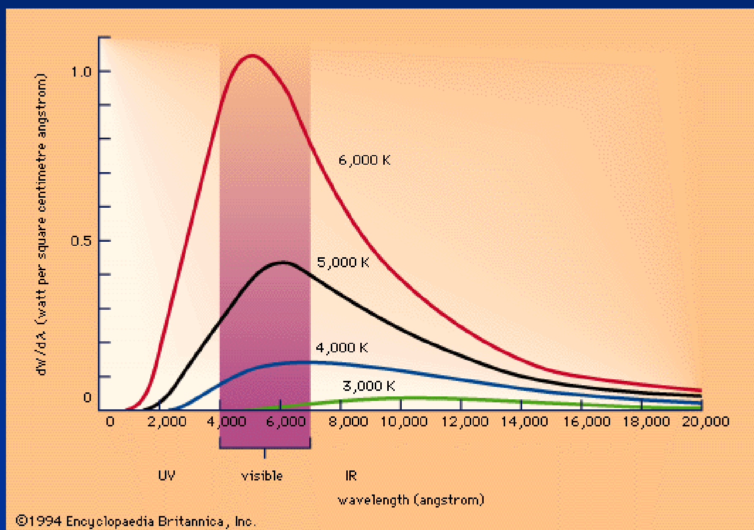
Optical spectra of Calcium

Heat Radiation



- Planck Thermal Radiation:

  Each mode carries discrete energy quanta: $E=h\nu$

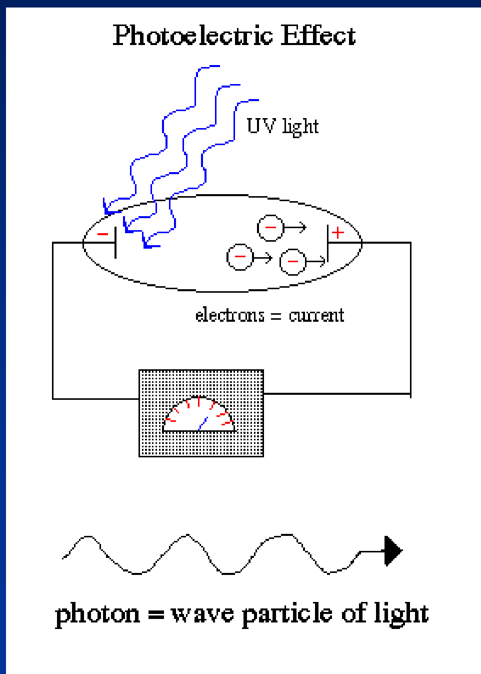


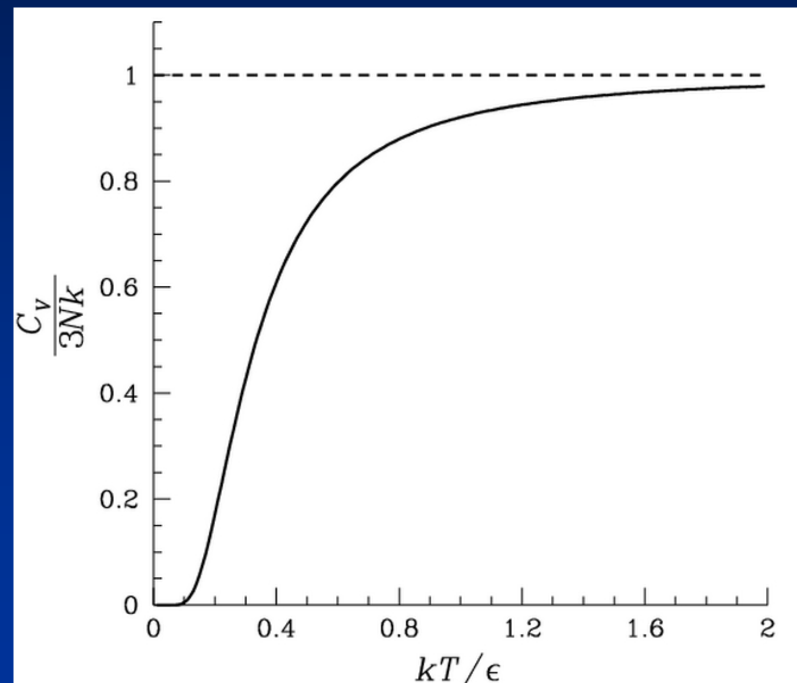
$$I=\frac{h\nu^3/c^2}{e^{h\nu/kT}-1}$$

Planck: I can characterize the whole procedure as an act of desperation, since, by nature I am peaceable and opposed to doubtful adventures. However, I had already fought for six years (since 1894) with the problem of equilibrium between radiation and matter without arriving at any successful result. I was aware that this problem was of fundamental importance in physics, and I knew the formula describing the energy distribution . . . hence a theoretical interpretation *had* to be found at any price, however high it might be.

Einstein: light energy is quantized

- Photoelectric effects: (1905)
- Specific heat in solids (1907)



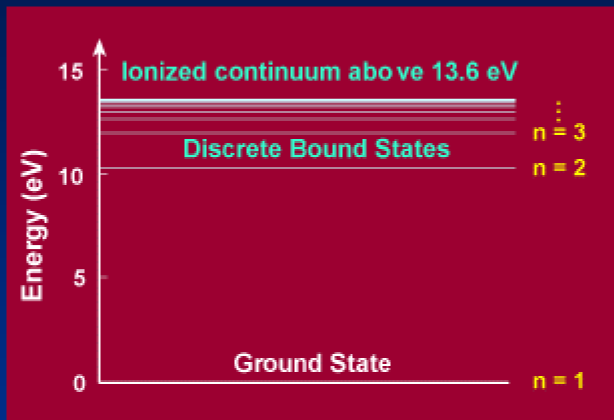


- Current is only generated with the frequency of the light higher than a threshold.
- No matter how large is the power of light, there is no electric current if the frequency of the light is below the threshold.

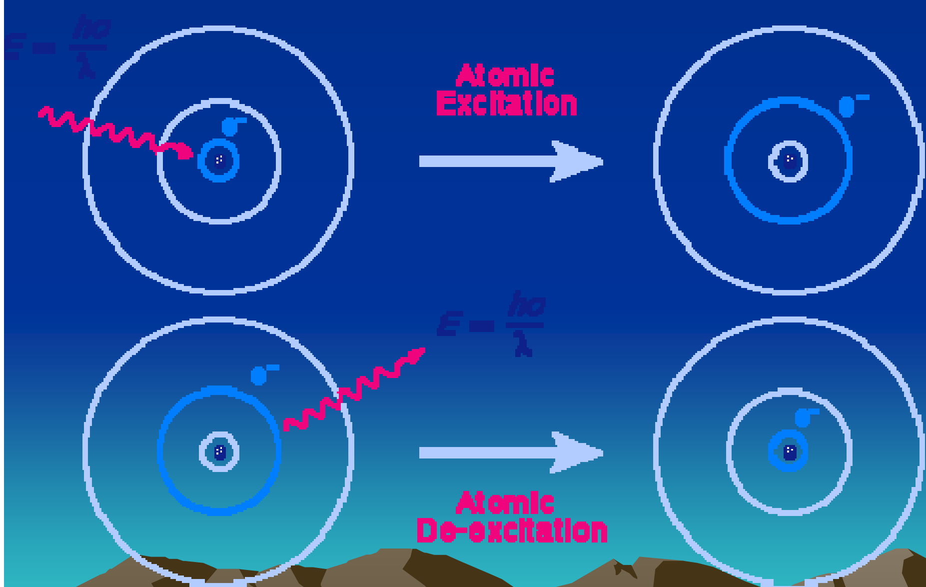
- Specific heat is a constant in classical statistical physics
- Einstein-Debye model: lattice vibration energy is quantized
- Specific heat is temperature dependent.

$$C_V = \frac{\partial E}{\partial T} = \frac{3N_A k \left(\frac{h\upsilon}{kT}\right)^2 e^{h\upsilon/kT}}{\left(e^{h\upsilon/kT} - 1\right)^2} \quad mole^{-1}$$

Bohr atom (1913)



- Electron orbits in an atom are quantized
- Each orbits have their own energy
- The absorbed light is exactly such that the photon carries the energy difference between the two orbits.



Bohr-Sommerfeld quantization:

$$\oint p\,dq = nh$$

The Birth of Quantum Mechanics

- Bohr's theory failed:

  At the turn of the year from 1922 to 1923, the physicists looked forward with enormous enthusiasm towards detailed solutions of the outstanding problems, such as the helium problem and the problem of the anomalous Zeeman effects. However, within less than a year, the investigation of these problems revealed an almost complete failure of Bohr's atomic theory. (Quote from Jagdish Mehra and Helmut Rechenberg: monumental history of quantum mechanics)

- Rapid development in 1920's
  (modern quantum mechanics)

  - Heisenberg Matrix theory (1925, age 23)
  - De Broglie wave=particle (1923, age 31)
  - Erwin Schrodinger wave equations (1925)
  - P.A.M Dirac: relativistic quantum mechanics (1926, age 22)
  - Linus Pauling: identical particle principle (1931, age 30)
  - Max Born: probabilistic interpretation of quantum mechanics

The Test of Quantum Mechanics

- Bohr-Einstein Debate
- Einstern-Podolsky-Rosen (EPR)

The measurement of a particle at one location could reveal instantly information about a second particle far away.

- Bell inequality(1964): tested. Quantum mechanics holds.

Today's Quantum Mechanics

- Controlling single particles: electron, photon, atom, spin
- Directly imaging quantum phenomena:
- Quantum Matter
  Low dimensional systems, artificial atoms, new states of matter
- Quantum Chemistry: design materials from the first principle
- Quantum Information and Quantum Computing
- Quantum Electronics
- Quantum Biology?