Major Concepts in Physics Lecture 16.

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http://physics/courses/PHY102.08Spring

So far …

- Prior to 20th century:
  - Mechanics (Newton)
  - Electromagnetism (Faraday, Maxwell)
  - Thermodynamics (Boltzmann, Gibbs)

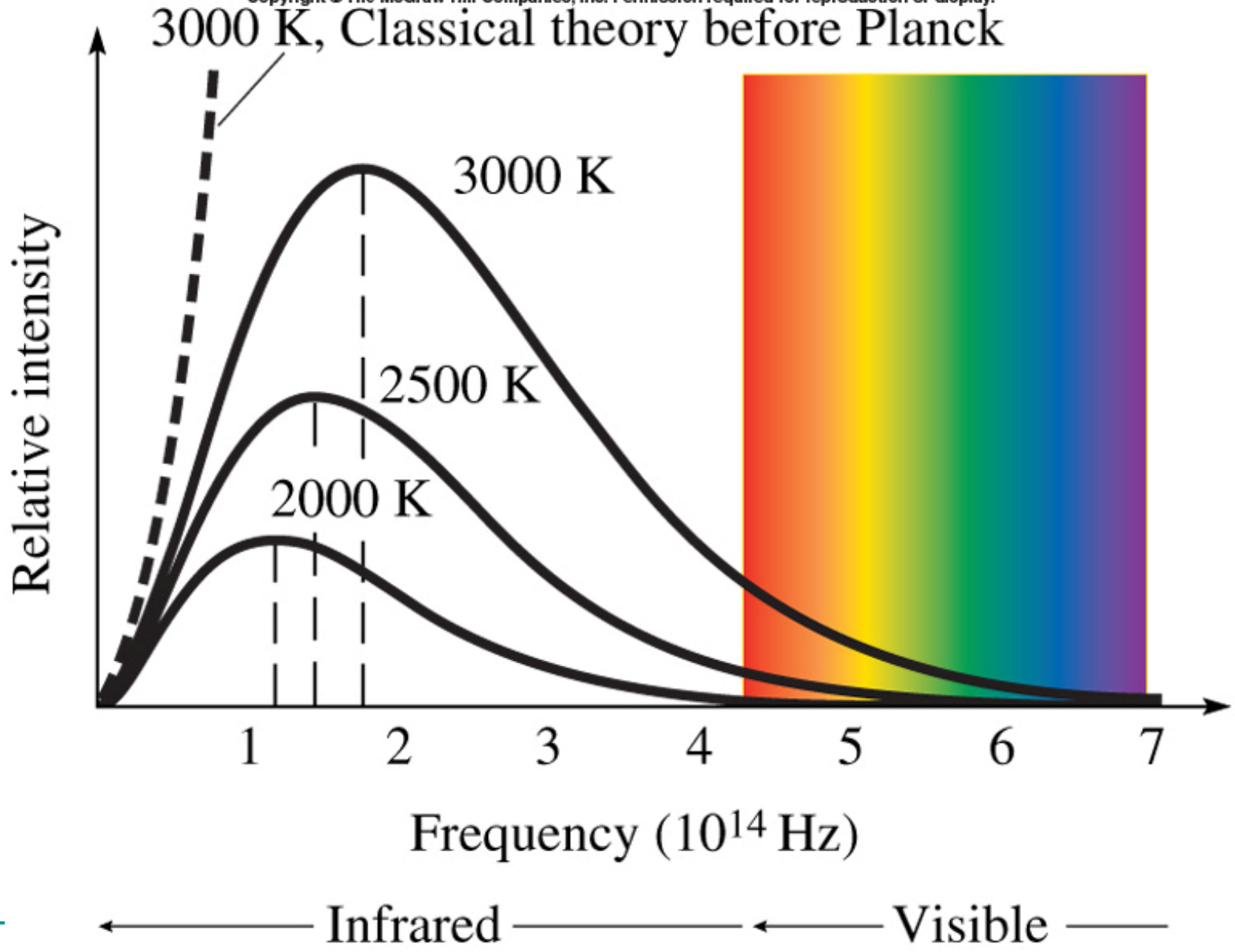
    classical physics …
- 20th century saw 2 dramatic revolutions
  - Relativity
  - Quantum Mechanics – experiments on atoms

A crisis

- Turn of 19th century series of experiments produced unanticipated results which were completely incompatible with classical physics
  - Blackbody radiation
  - Structure of atoms
  - Photoelectric effect
  - ….

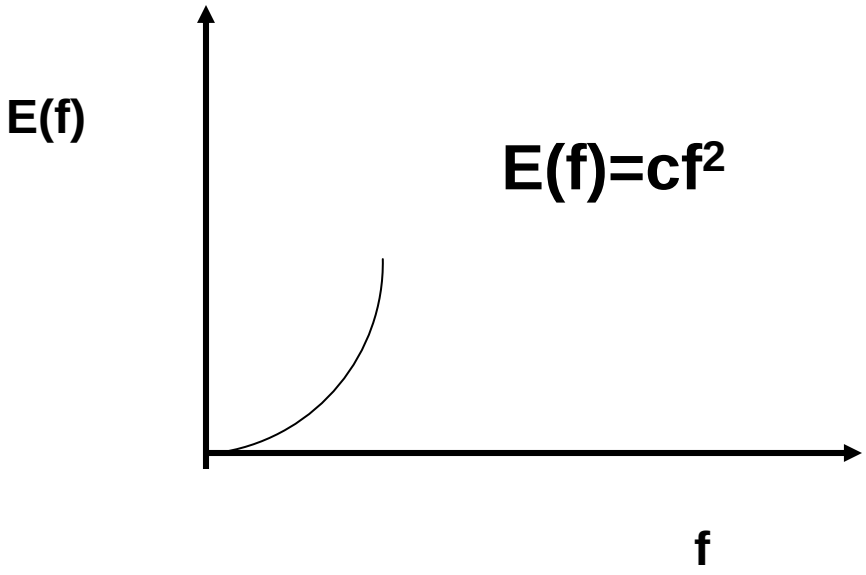
Blackbody curves

- We have seen that thermal radiation is emitted with a distribution of intensity which depends on frequency
- Wien's law tells us how the peak moves with frequency, Stefan what the total amount of emitted radiation is …
- Curves were determined very accurately via experiments



Ultraviolet catastrophe …

- Unfortunately classical physics was not able to account for the shape of these curves



$E(f)=cf^2$

Total radiation emitted = infinite!

To correctly explain the shape of the blackbody spectrum Planck (1900) proposed that the energy absorbed or emitted by oscillating charges came in discrete bundles called **quanta**. The energy of the quanta are

$$E_0 = hf$$

where $h=6.626\times10^{-34}$ J s is called Planck's constant.

The quantum of EM radiation is the **photon**.

Radical

- Note: real crisis: classical answer=infinite. Experiment is finite.
- Classical physics says any frequency is possible
- Planck says – no, EM radiation is emitted/absorbed only in discrete amounts.
- Ad hoc. Why ?

There is more …

- About the same time experiments showed that when light hit a metal surface electrons were emitted – photoelectric effect
- Problem is that the details of how this happens seemed again to contradict classical physics …

Fig. 27.4

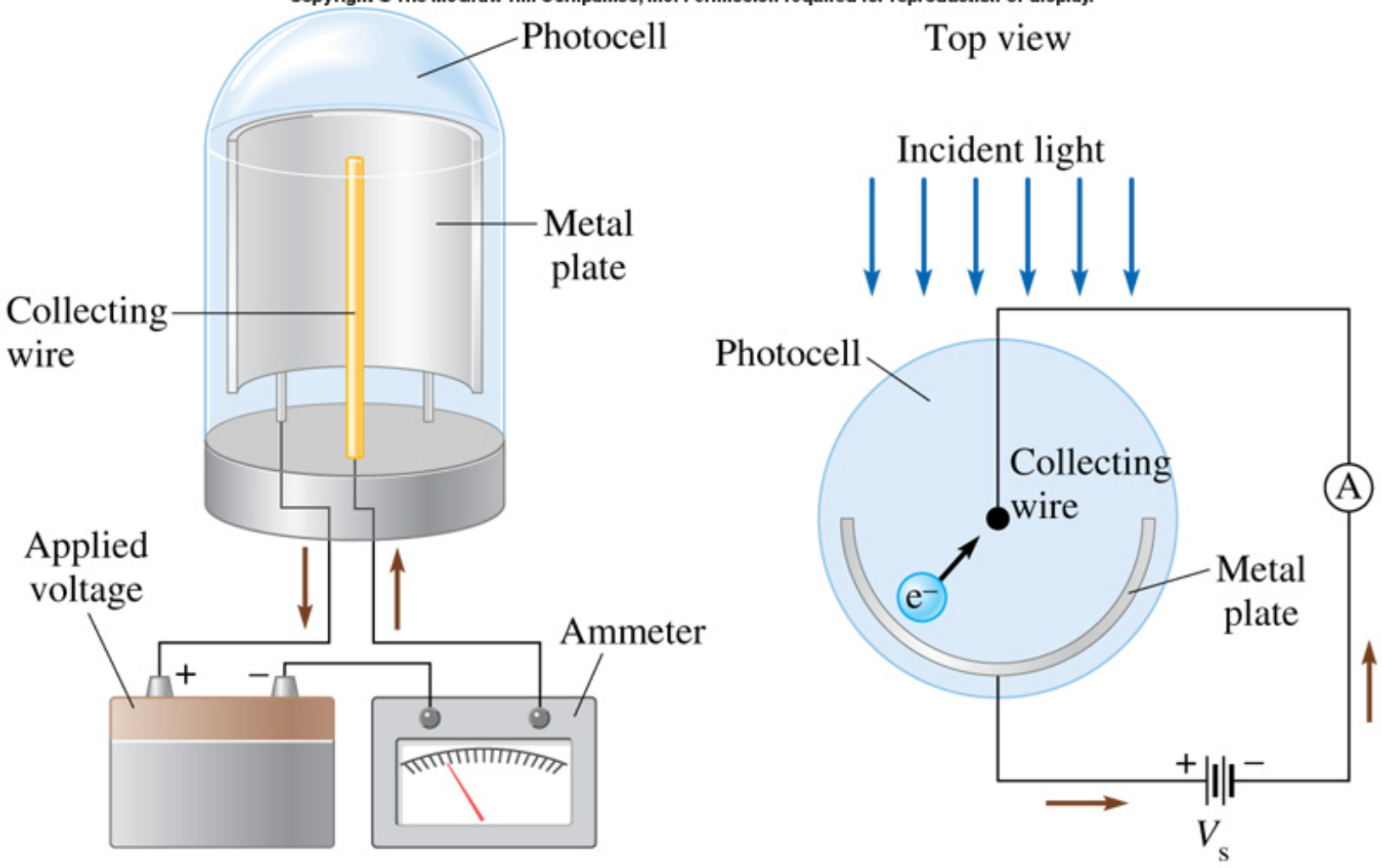
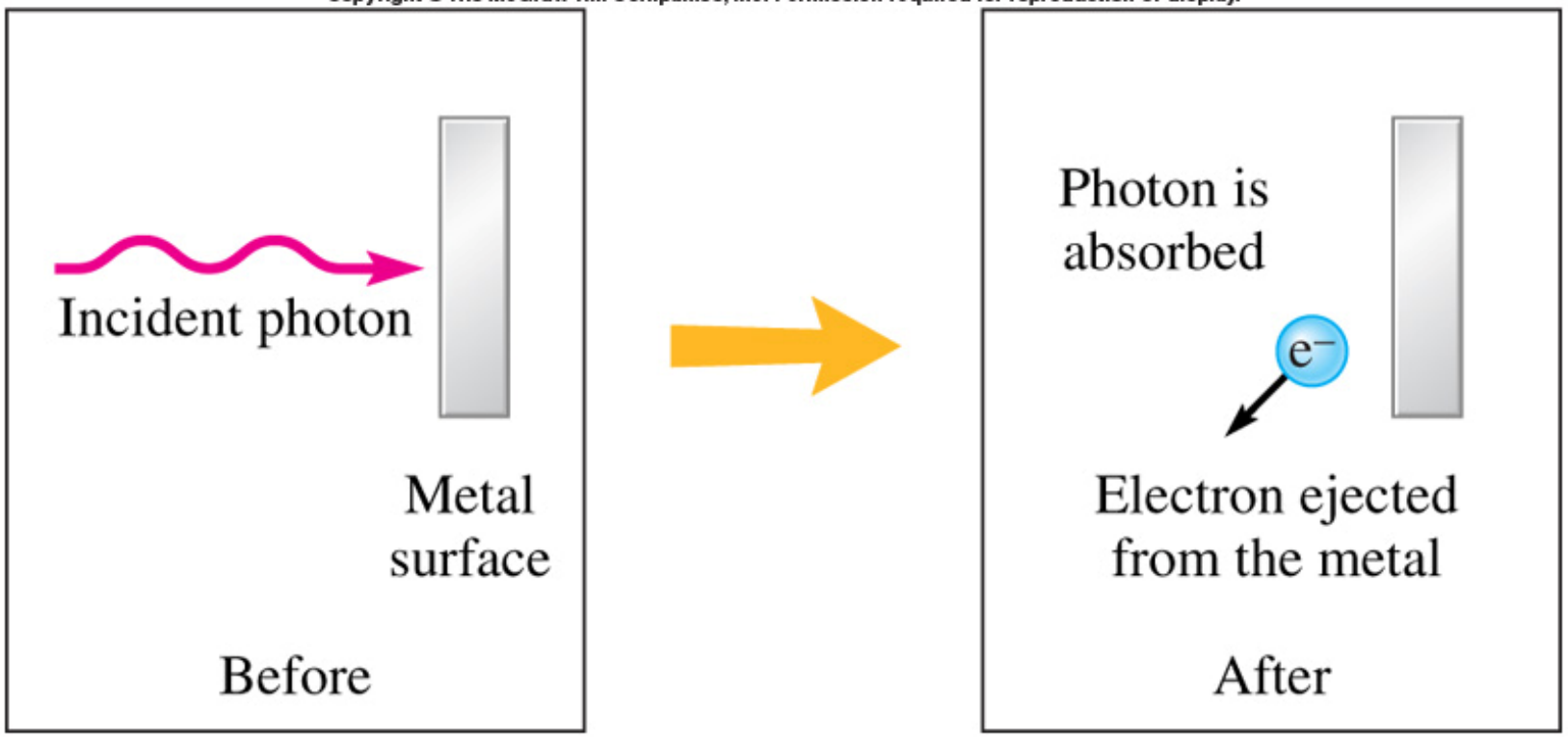


Fig. 27.6

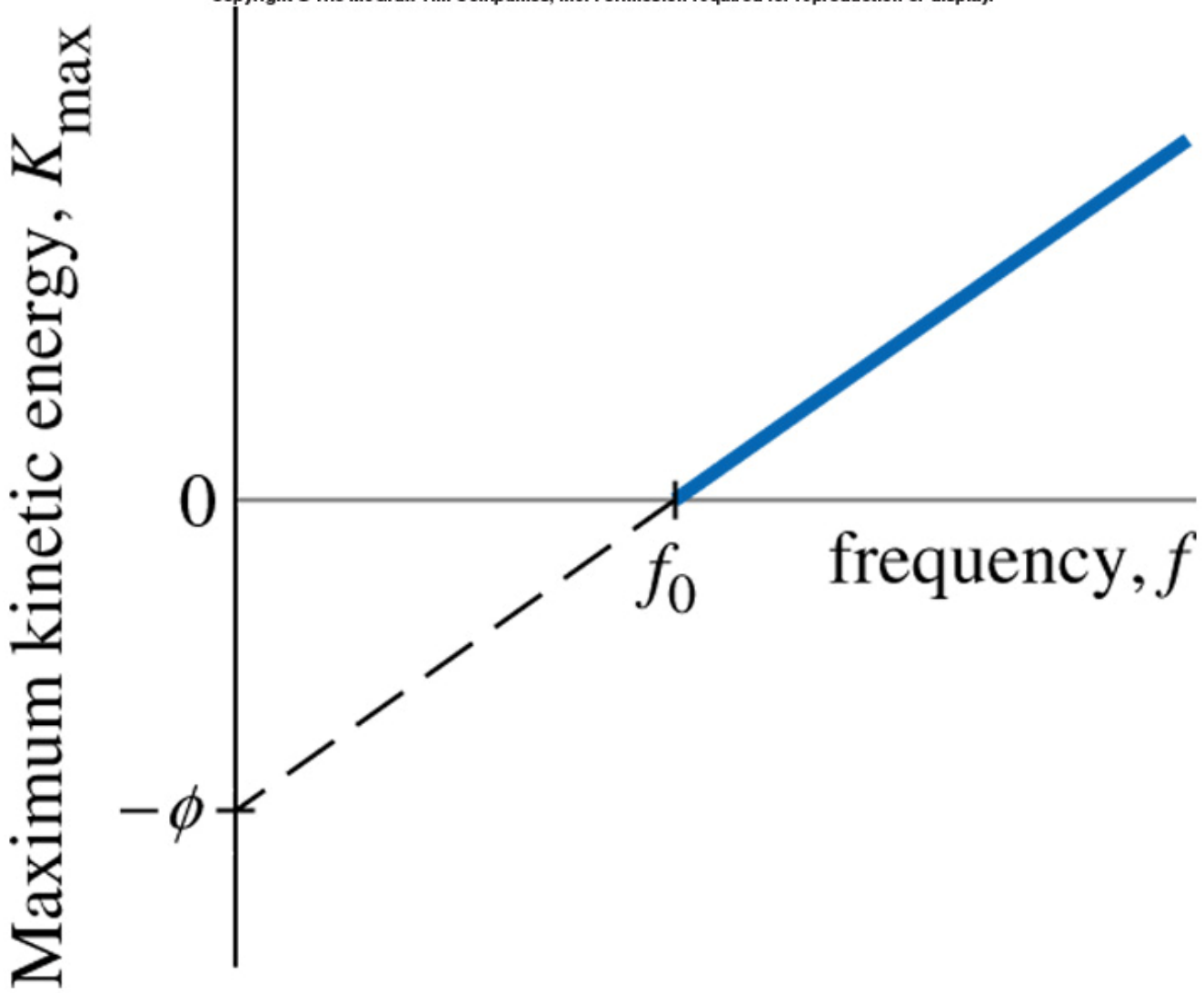


Photoelectric effect demo

- Note: see electric current as emitted electrons collected by anode and flow in circuit
- Add battery: serves only to collect more electrons – not responsible for current.
- Current increases with visible light
- Still non zero with blue light BUT DISAPPEARS with red !

Further refinements

- Find
  - Maximum kinetic energy of electrons does not depend on the intensity of light
  - Max kinetic energy does depend on the frequency of light
  - As we seen we only see electrons if the frequency exceeds some threshold …



Problem for classical physics

- Classical wave theory would predict that electron energy should just depend on light intensity, not frequency.
- There should be no minimum frequency and no maximum to electron energy

Einstein's explanation (1905)

- Planck says: EM radiation may only be emitted/absorbed in discrete amounts hf
- Einstein: Perhaps EM radiation in vacuum consists of only these discrete packets of energy – photons
- Light is not a wave at all but a stream of photons !!

But we just spent 8 weeks arguing that it was a wave !!

What is the energy of a photon of red light (wavelengh 670 nm) ?

- A: 3×10^{-19} J
- B: 3×10^{-15} J
- C: 1.5 J
- D: 6×10^{-15} J

Photoelectric equation

$$K_{max}=hf-\phi$$

Φ is called the work function of the metal.

It measures the minimum amount of energy required to eject an electron from within the metal

Conclusions

- More light intensity means more photons per minute and hence ejected electrons
- But, an individual electron is knocked out by colliding with a *single* photon – which must have a minimum of energy to do the job
- Higher frequency light has more energetic photons and hence lead to larger electron energies

Atoms

- Seen earlier that light emitted by single element contains only a discrete set of possible frequencies.
- This is also a puzzle for classical physics. An electron orbiting a nucleus could radiate light at a frequency equal to its orbital frequency. But that is unrestricted → so the emitted radiation should also be at all frequencies

Worse still …

- Actually this loss of energy in the form of EM waves should lead to a decaying electron orbit – energy is continuously being lost
- If one works out how fast before the electron decays into the nucleus one finds a very short time – 10^{-8} s !!
- So matter is not even stable classically …

Summary

- Classical physics fails completely to describe what happens in atoms
  - Infinite radiation energies, photoelectric effect, line spectra, …
- Partial explanation due to Planck/Einstein. Treat light (a wave) as a particle the photon with energy E=hf
- Conversely discrete line spectra look like wave phenomena – for the electron (particle)

Resolution

- Requires a completely new theory of matter and motion – quantum mechanics
- Contains within in description of both waves and particles as two sides of same coin

wave-particle duality