Intro to Quantum Mechanics

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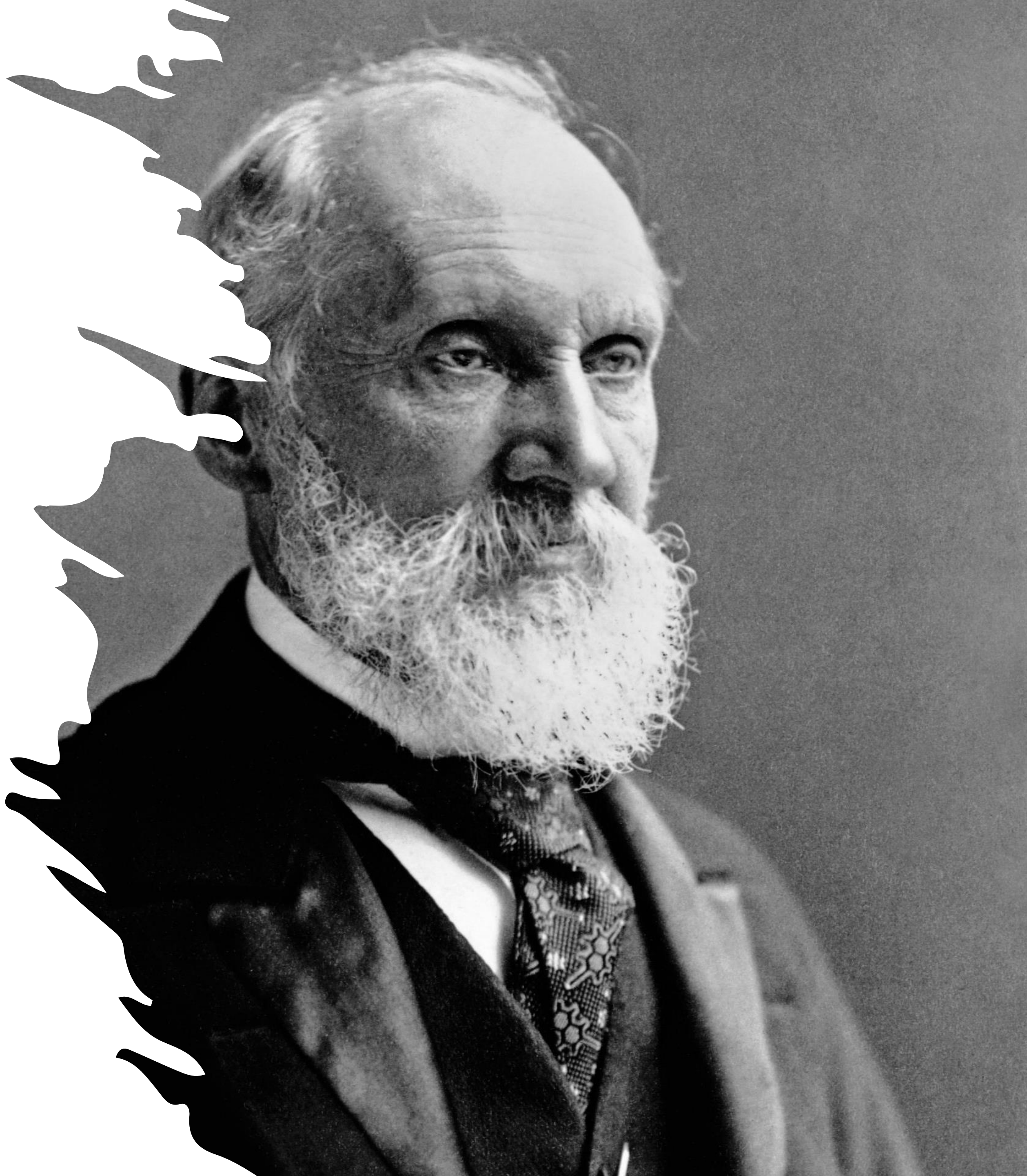
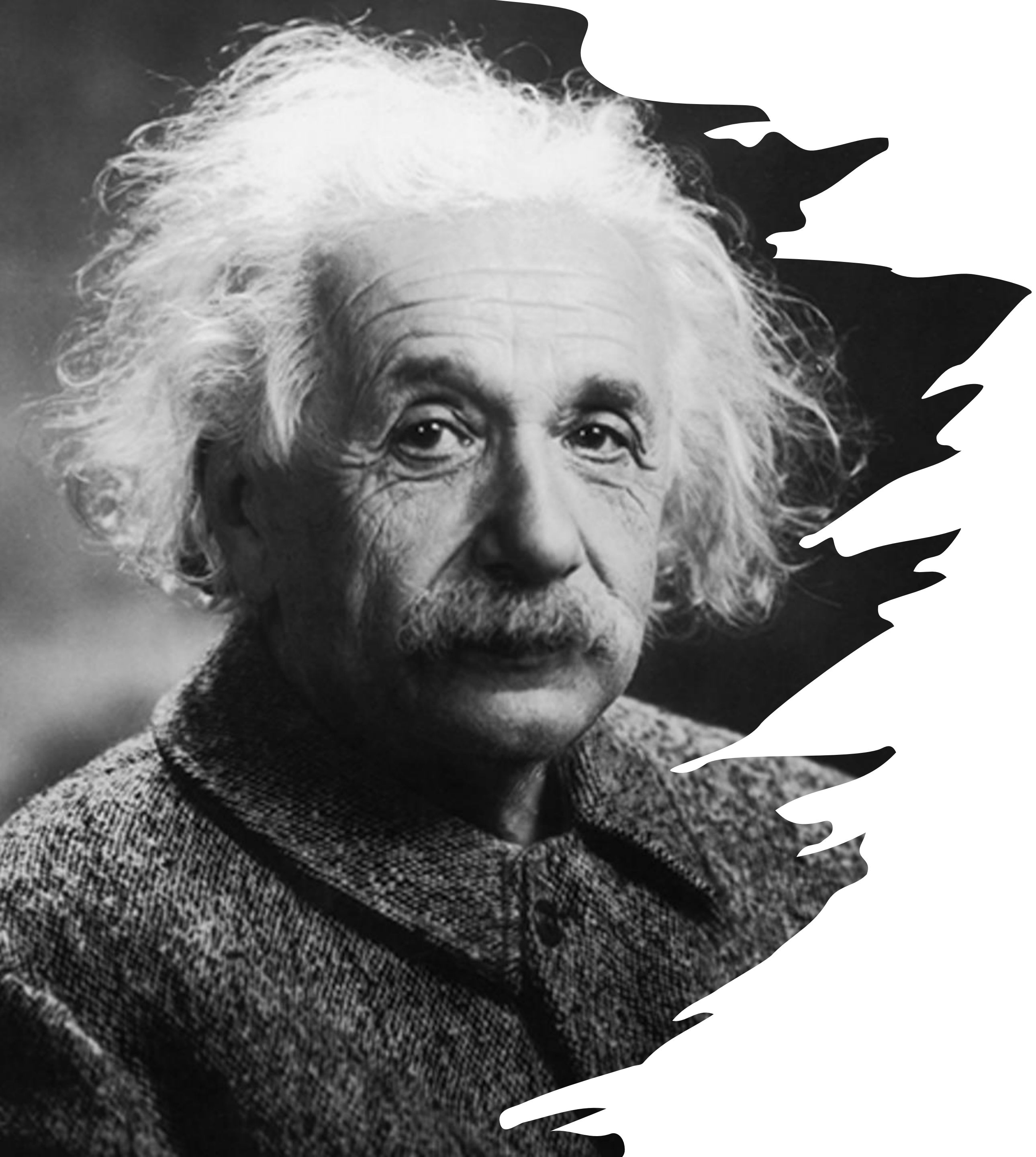
Solving the Schrodinger's Equation

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = \left[-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x,t)\right]\Psi(x,t).$$

A historical approach to quantum science

- Everything started with the two “clouds”
- In 1900, Lord Kelvin claimed that the foundation of physics was established, and all future physicists needed to do were making better measurements
- He said that there were only two “clouds” on the monument of physics: the relative motion of the ether with respect to massive objects and Maxwell–Boltzmann's theorem on the equipartition of energy.



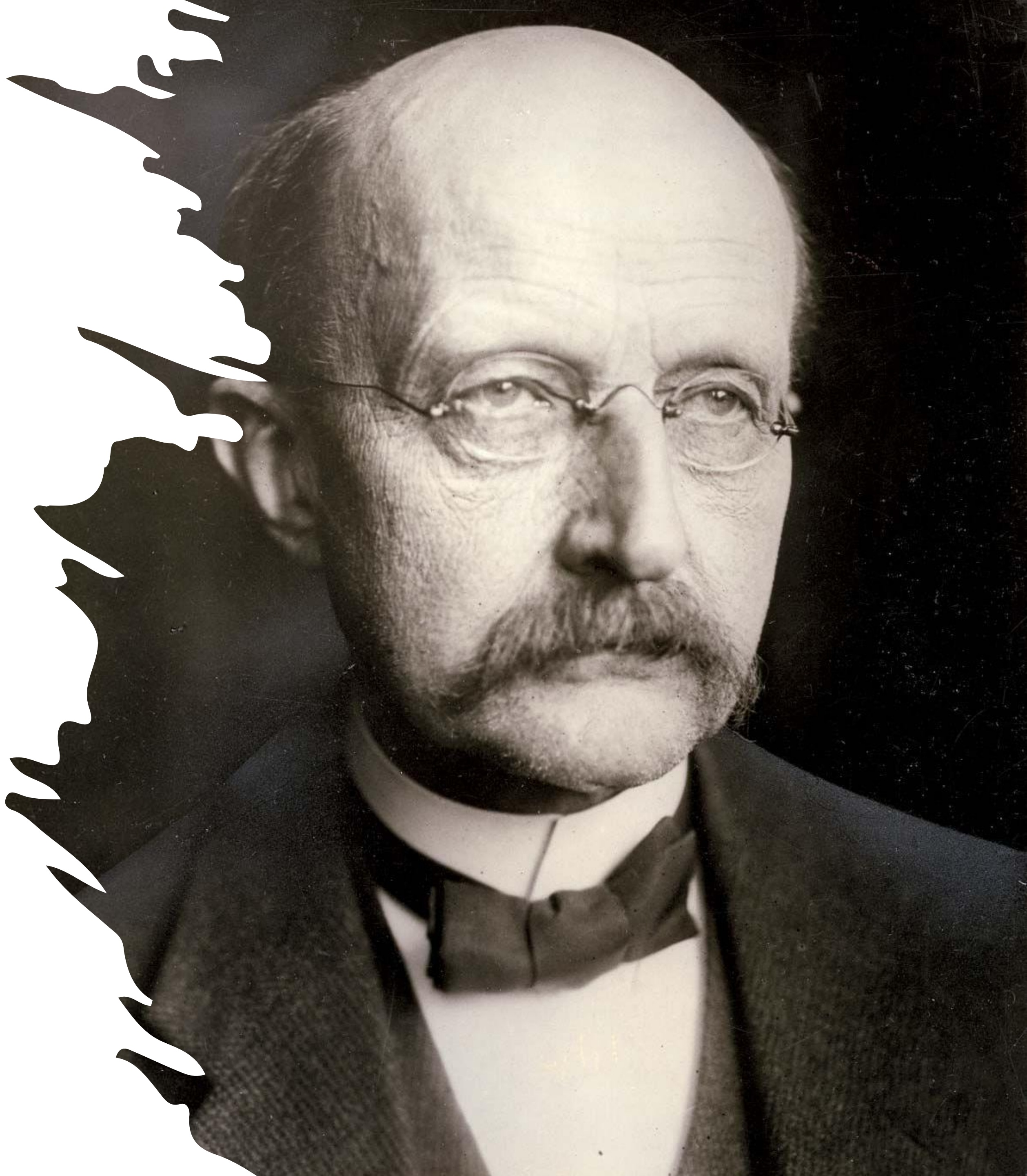


A decisive line between classical physics and modern physics

- Lord Kelvin was correct in some sense. If the two clouds did not exist, physics would have been so much simpler to learn (though that’d be so boring lol)
- The two clouds later evolved into almost the entirety of modern physics
- The discussion around ether sparked the idea that ether did not exist at all, but instead the speed of light is constant. From there, specific relativity was theorized, and later general relativity.

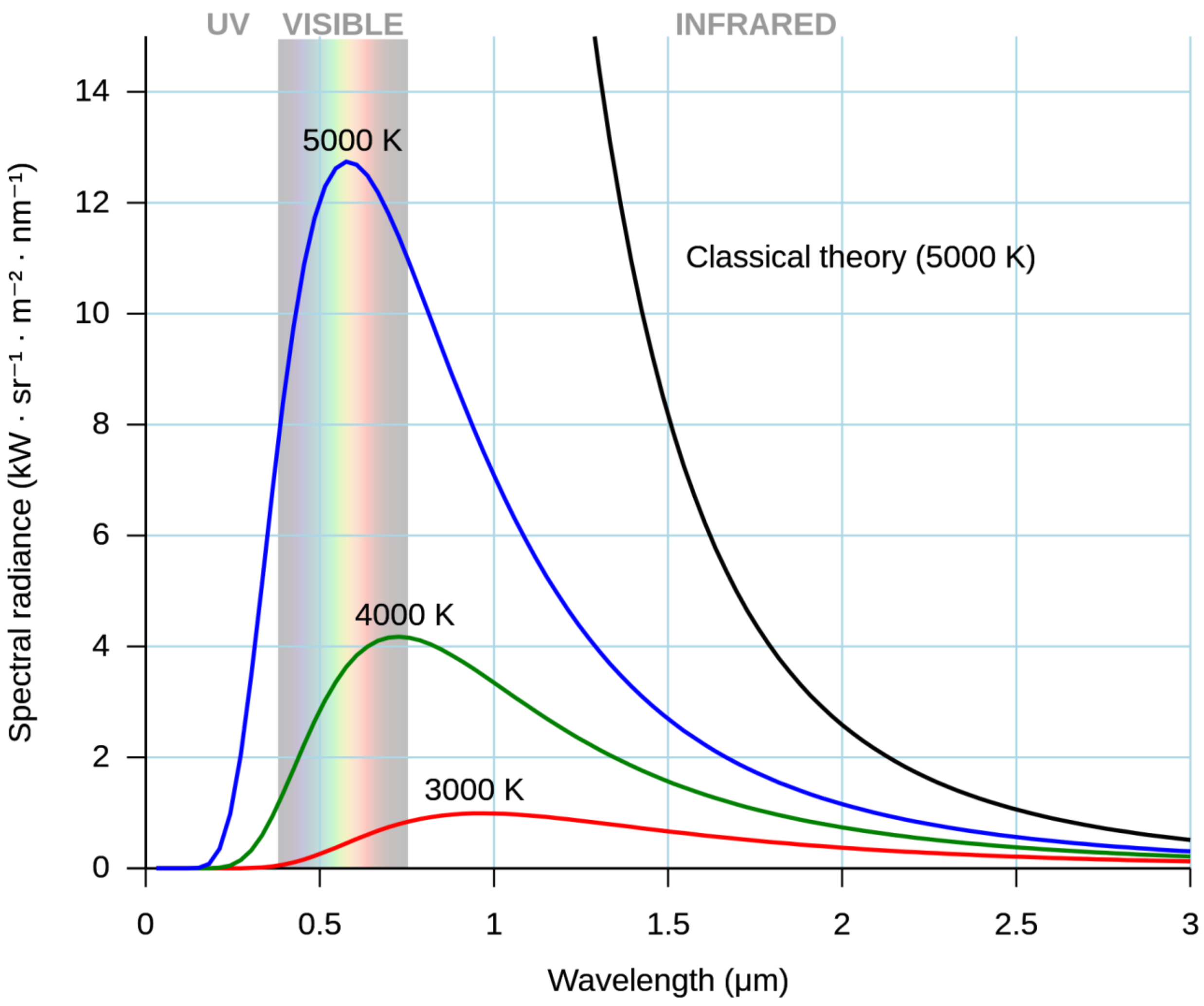
A decisive line between classical physics and modern physics

- The second cloud is better known as the "ultraviolet catastrophe"
- People knew back then already that light were waves thanks to Maxwell's monumental work on electric and magnetic waves; namely, Maxwell's equations
- When dealing with black body radiation, a peculiar phenomenon existed: Rayleigh-Jeans law
- $B_\nu(T) = \frac{2ck_BT}{\lambda^4}$



Wow! Infinite energy!

- Well, obviously that can't happen

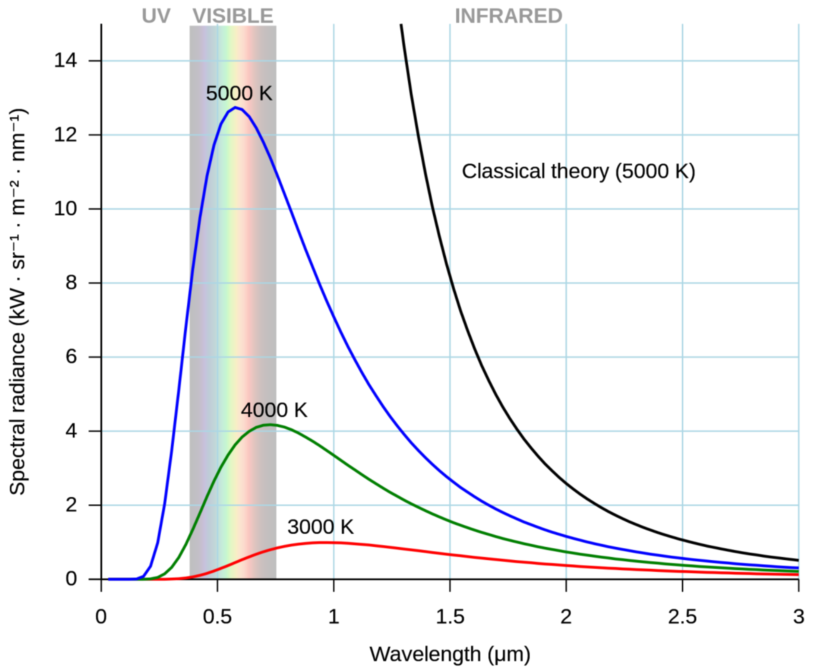


A slight tangent

- We are so used to seeing the previous two pictures of Albert Einstein and Max Planck, but what did they really look like when they came up with relativity or energy quantization?

Planck made an astonishing assumption

Energy Is Quantized



$$B_\upsilon(T) = \frac{2\upsilon^2}{c^2}\frac{h\upsilon}{e^{h\upsilon/kT} - 1}$$

Well, not exactly

- What actually happened was that there were two different expressions, one working well for low frequency (long wavelength) and one working well for high frequency (low wavelength)
- For a long time, people saw Planck’s work as a clever mathematical trick and did not see the implications
- In 1905, Einstein came in and interpreted the result of Planck’s equation as light packets that carry a quantized energy
- A term was later coined: photon

Tangent: wave-particle duality

- As far back as ancient Greece, philosopher Democritus already proposed the idea that everything is made of atoms
- John Dalton developed the atomic theory in 1808, and that became very important for chemistry
- It was a natural idea to envision light as particles, since everything else were made of atoms… until it wasn’t
- Maxwell, in 1865, published his famous Maxwell Equations, establishing basically half of classical physics: electromagnetism. These equations and the related experiments (double slit interference) convinced most people that light was an electromagnetic wave

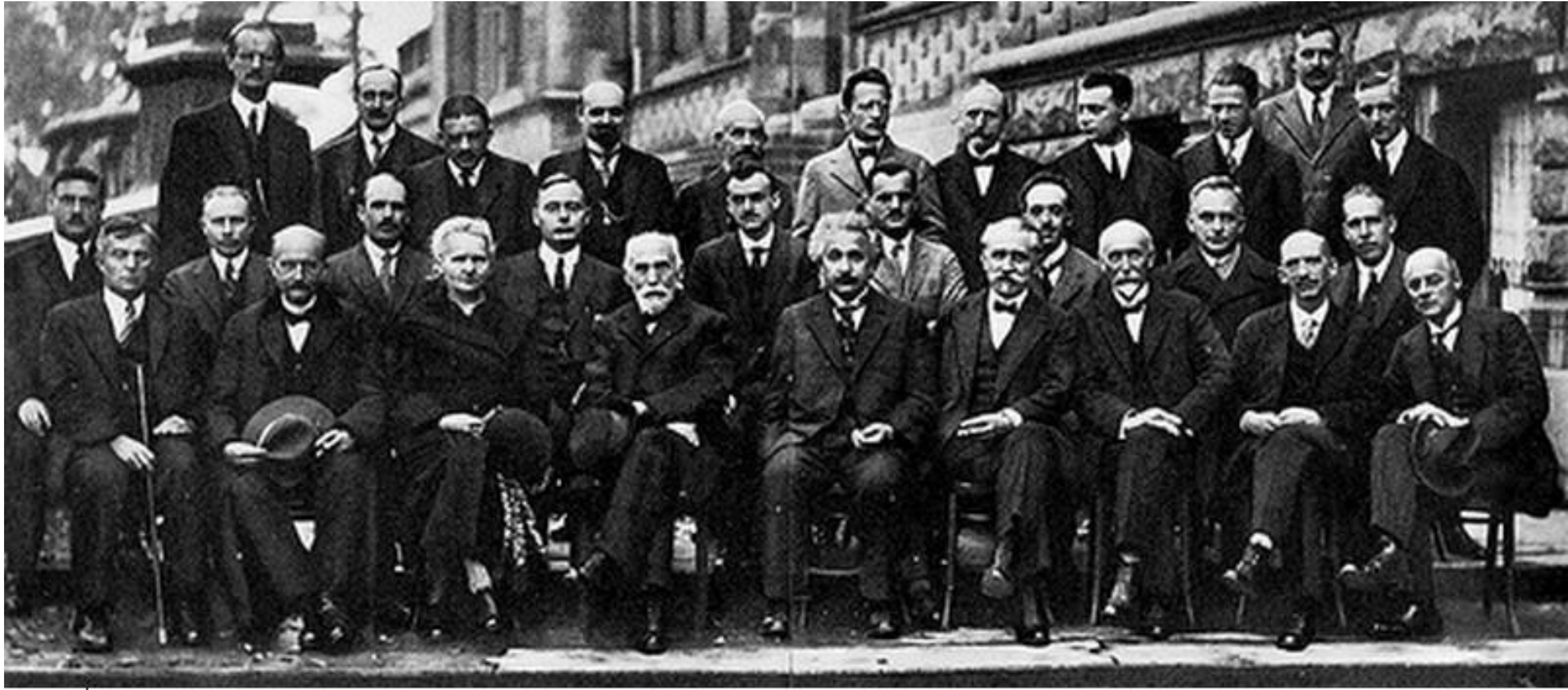
So why should people accept photon now?

- In 1897, J.J. Thompson discovered electrons as an explanation of cathode rays
- In 1902, Phillip Lenard discovered a peculiar phenomenon of the individual energy of electrons leaving a material during the photoelectric effect
- With the same light source, the energy of emitted electron does not increase with higher light intensity. More electrons are emitted
- This does not agree with the theory that light is a wave
- In 1905, Einstein took his interpretation of Planck’s work a step further and applied the idea of photon to the photoelectric effect
- It… kinda just makes sense

What does quantization imply for modern science?

- The idea of quantization soon found its way into Atomic Physics, which at the time, was heavily related to chemistry
- After the nucleus was discovered in 1909 with the Rutherford’s Experiment, people start wondering about how electrons could revolve around the nucleus
- Niels Bohr came up with a brilliant explanation for electrons’ movement around the hydrogen nucleus (we are going to solve this in later lectures)
- De Broglie took a step further and theorized that everything can be waves, even electrons, atoms, and macroscopic objects
- Matter wave… well, that’s an entire new field of physics with a lot of open questions

Solvay Conference of 1927



Front Row:

I. Langmuir, M. Planck, Mme. Curie, H.A. Lorentz, A. Einstein, P. Langevin, Ch. E. Guye, C.T.R. Wilson, O.W. Richardson

Middle Row:

P. Debye, M. Knudsen, W.L. Bragg, H.A. Kramers, P.A.M. Dirac, A.H. Compton, L. de Broglie, M. Born, N. Bohr

Back Row:

A. Piccard, E. Henriot, P. Ehrenfest, Ed. Herzen, Th. De Donder, E. Schrödinger, E. Verschaffelt, W. Pauli, W. Heisenberg, R.H. Fowler, L. Brillouin

Interpretations of Collapsing of Quantum States

- Hidden Variable
- Copenhagen interpretation
- Many Worlds Interpretation
- Many History Interpretation

Conclusion

- The modern physics rely heavily on quantum mechanics
- QM was not developed by a few geniuses, and it was not a "revolution"
- Instead, QM was more like an inevitability
- As people know more and more about the world and have better equipment to do experiments, QM gets developed to explain why the experimental results exist
- Ok, so our physical world is dominated by QM. Now what?