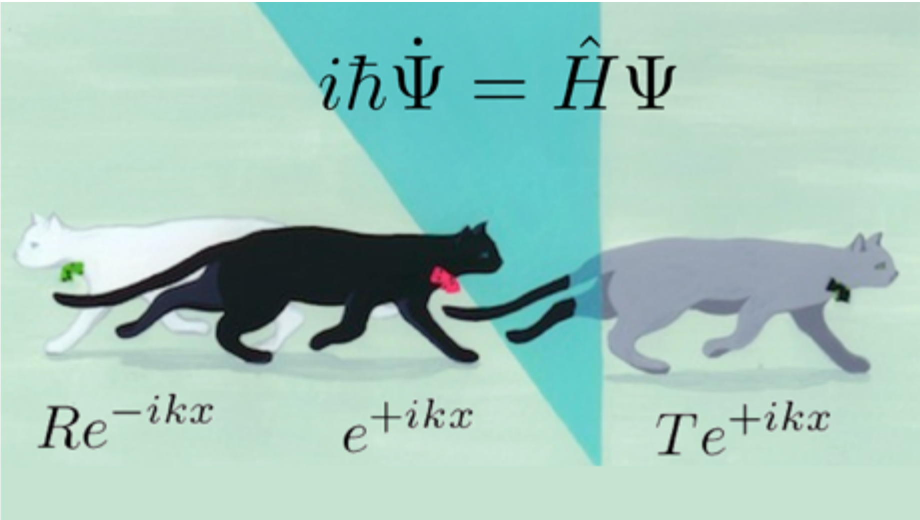
Exploring Quantum Physics

Coursera, Spring 2013 Instructors: Charles W. Clark and Victor Galitski

Atomic Structure and Spectra

Part II. Interference and diffraction



Atomic Structure and Spectra

Tools for controlled dispersion of light: refraction and **diffraction**

The **interference** of wave motions is a matter of common experience. Thomas Young built a simple ingenious device to demonstrate that light is a wave.

Atomic Structure and Spectra

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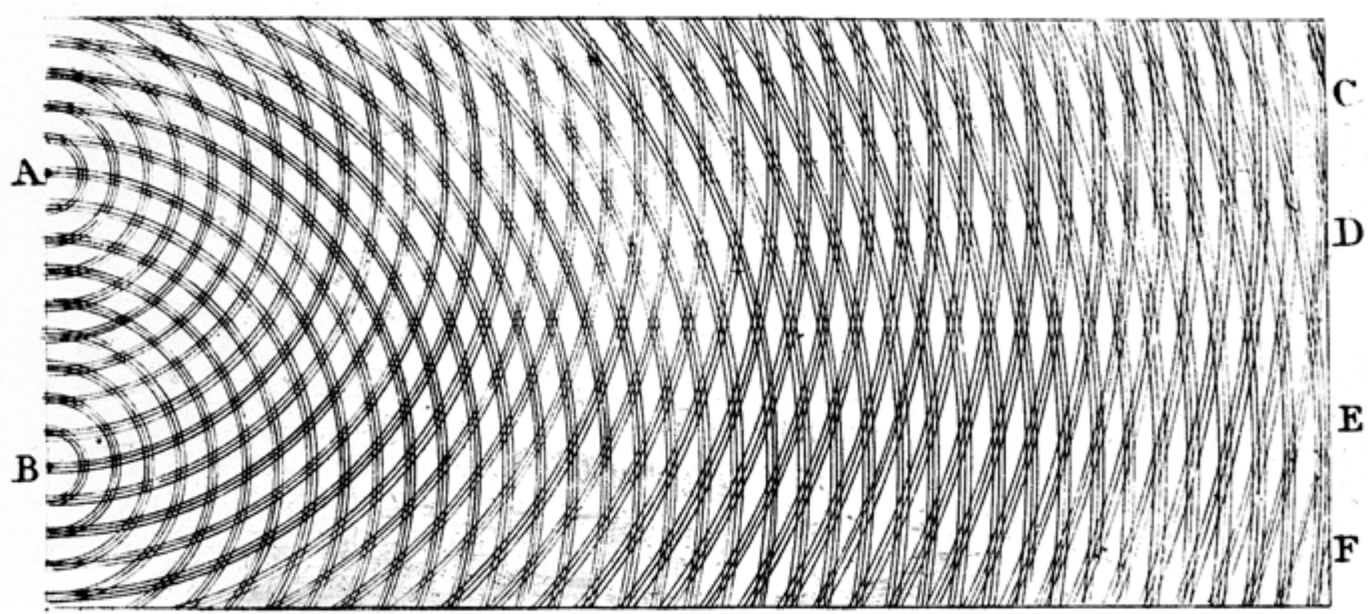

Young 1809

Thomas Young's ingenious double slit experiment demonstrated the wave nature of light and made possible the **quantitative measurement of its wavelength.**

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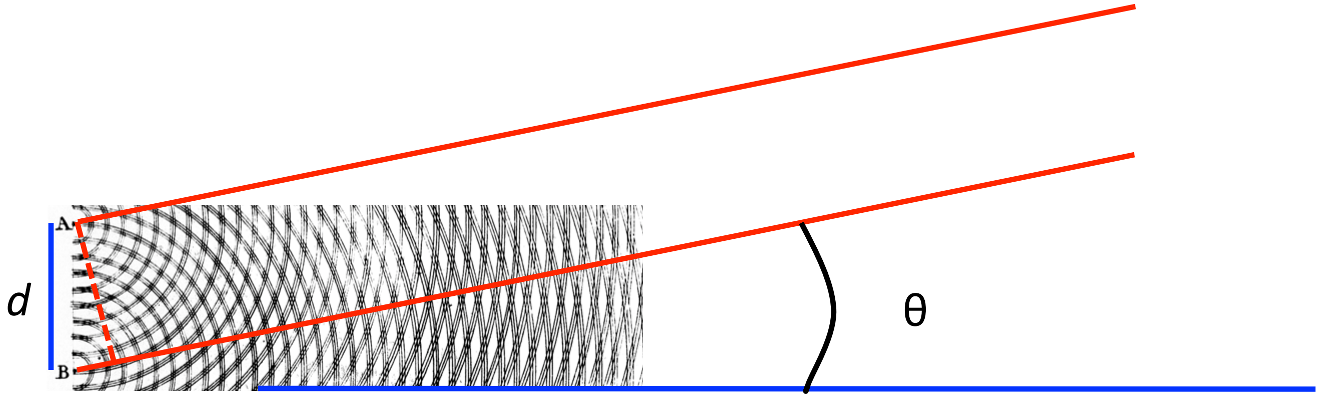

Young 1809

$$\delta = d\sin(\theta) = m\lambda, \qquad m = 0, \pm 1, \pm 2, \ldots$$

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V "From a comparison of various experiments, it appears that the breadth of the undulations constituting the extreme red light must be supposed to be, in air, about one 36 thousandth of an inch, and those of the extreme violet about one 60 thousandth; . . . From these dimensions it follows, calculating upon the known velocity of light, that almost 500 millions of millions of the slowest of such undulations must enter the eye in a second." – Thomas Young, 1803

$\lambda\nu = c$

Even today, direct measurement of 5 x 10^{14} Hz frequencies is not routine. **2005 Nobel Prize in Physics** to John L. Hall and Theodor W. Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique."

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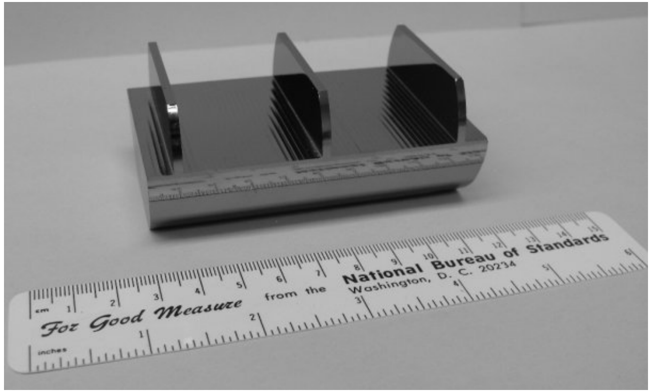
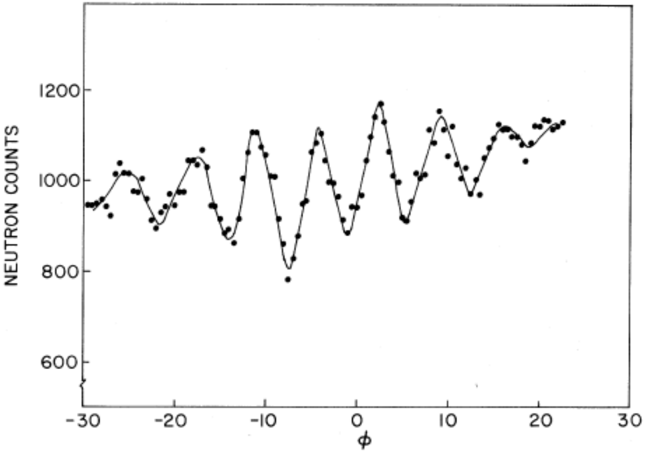
Interferometry has since been done with electrons, neutrons, atoms and even large molecules.

Courtesy Sam Werner





Neutron interferometer, of type first used to measure effect of gravity on a quantum particle: $\lambda_{dB} \sim 10^{-10}$ m
R. Colella, A. W. Overhauser and S. A. Werner, "Observation of Gravitationally Induced Quantum Interference," *Physical Review Letters* **34**, 1472 (1977)

Atomic Structure and Spectra

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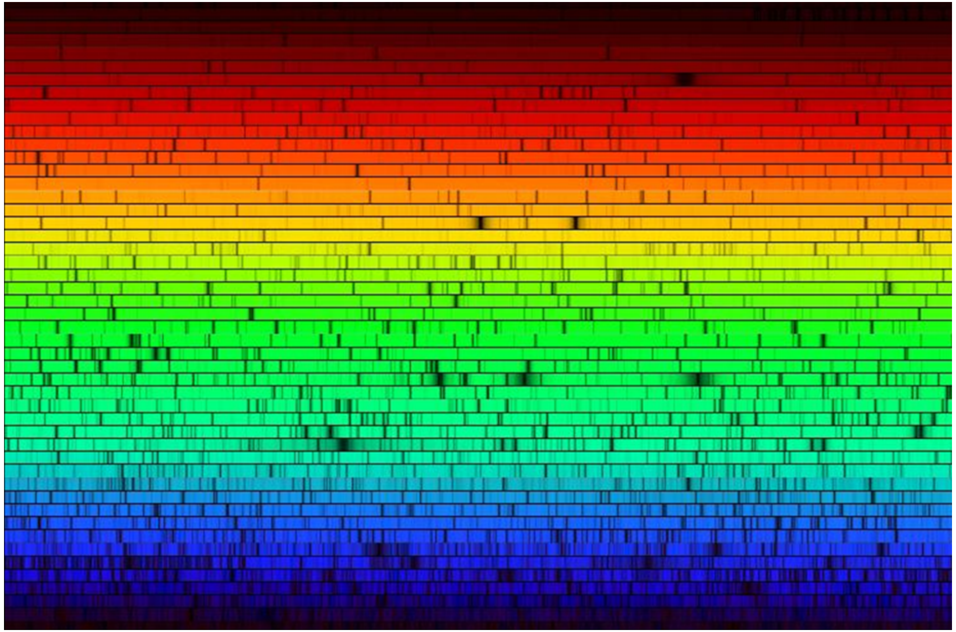
λ = 650 nm R

λ = 532 nm G

λ = 405 nm V



Nigel Sharp, National Optical Astronomical Observatories

When seen under high resolution, there are numerous **dark lines** in the spectrum of the Sun. This pattern was decoded using the techniques we discuss this week.

Atomic Structure and Spectra

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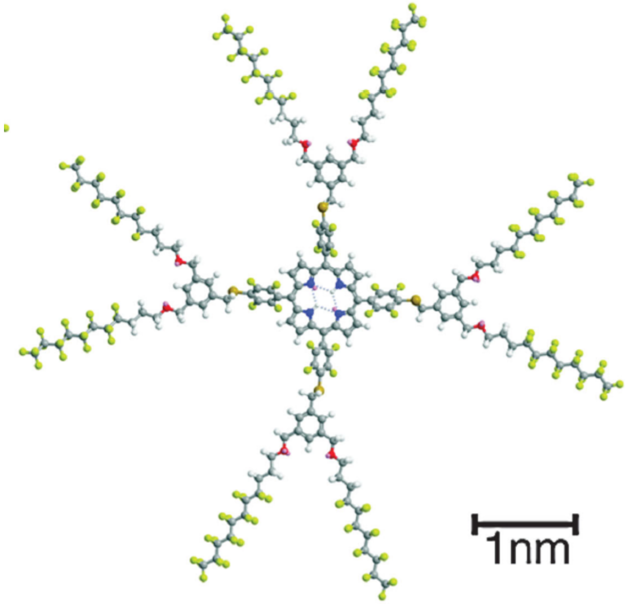
Interferometry has since been done with electrons, neutrons, atoms and even large molecules.

TPPF152, a derivative of tetraphenylporphyrin (TPP) that contains 152 fluorine atoms. Quantum interference observed at deBroglie wavelengths λ_{dB} of 10^{-12} m.

K. Hornberger, S. Gerlich, P. Haslinger, S. Nimmrichter and M. Arndt, "Colloquium: Quantum interference of clusters and molecules", *Reviews of Modern Physics* **84**, 157 (2012)



Atomic Structure and Spectra

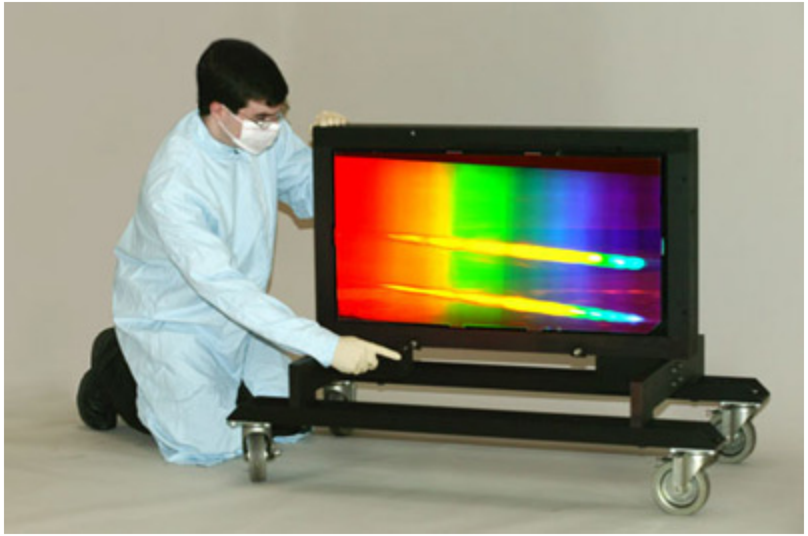
Tools for controlled dispersion of light: refraction and **diffraction**

Fraunhofer also developed the **diffraction grating**, one of the most powerful passive devices ever conceived.

- Makes possible direct measurements of wavelengths
- Essential component of modern fiber-optic telecommunications infrastructure

Fundamental **grating equation**:

$$m\,\lambda = d \sin\theta \quad m = 0, \pm 1, \pm 2, \ldots$$



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See course Additional Material: Young's double slit experiment and diffraction

Inline quiz

Why is the optical spectrum usually described in terms of wavelength λ rather than frequency ν?

The wavelength is a more fundamental concept than the frequency.
No. $\lambda\nu = c$, the speed of light. The two are equivalent.

The wavelength of a light ray stays the same when light travels between vacuum and glass or air, but the frequency changes.
No. That statement is false

The international standard of length, the meter, is defined in terms of the wavelength of a spectral line of the krypton atom.
No. The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

The wavelength of light is more convenient to use in quantum mechanical calculations than is the frequency.
Usually not. Interaction of light with matter depends primarily on differences in energy levels, which are proportional to frequency.

Precise measurements of optical wavelengths became possible long before precise measurements of optical frequency.
Yes. Diffraction gratings made precision wavelength measurements possible in the 19th century, when there was no capability for measuring ~ 500 terahertz optical frequencies

Engineering design of important technological applications such as wavelength division multiplexing is more efficiently described in terms of wavelength than frequency.
Yes. Diffraction grating design and implementation is primarily determined by wavelength, not frequency.

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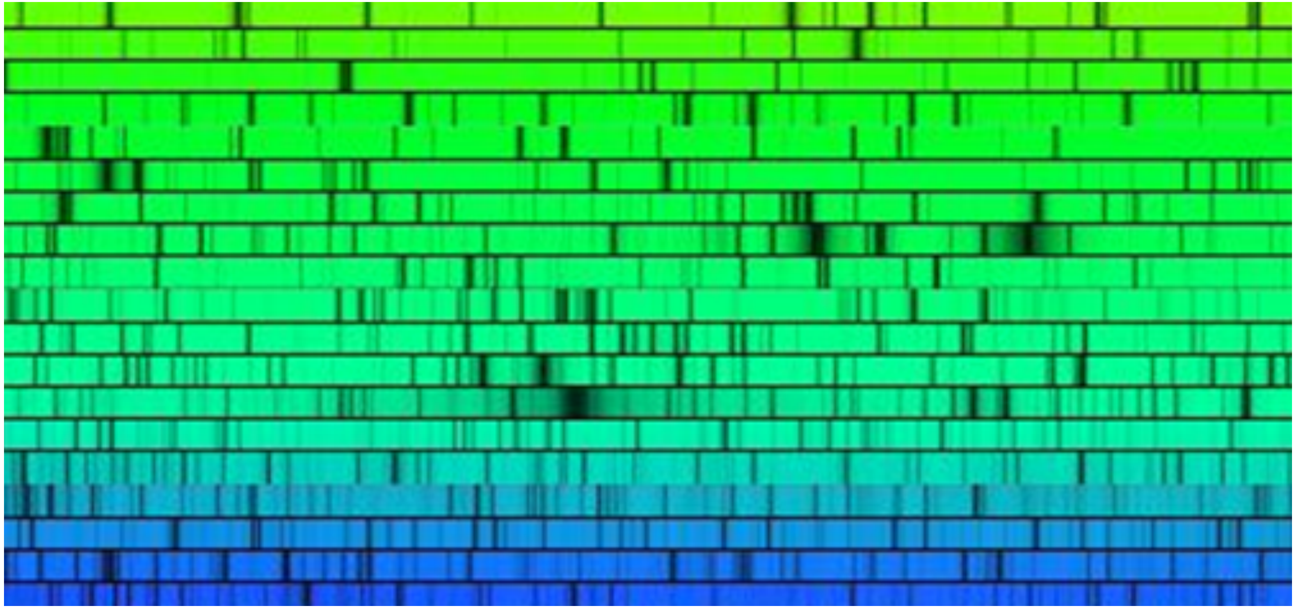

Nigel Sharp, National Optical Astronomical Observatories

Fourier transform spectrometer with resolving power $\lambda/\Delta\lambda \sim 500{,}000$

Atomic Structure and Spectra

Nick Ares, Wikimedia Commons

Gases of atoms and simple molecules often produce light of vivid appearance when they are excited in electric discharges.

The neon marquee sign of the 1937 State Theater in Auburn, California.

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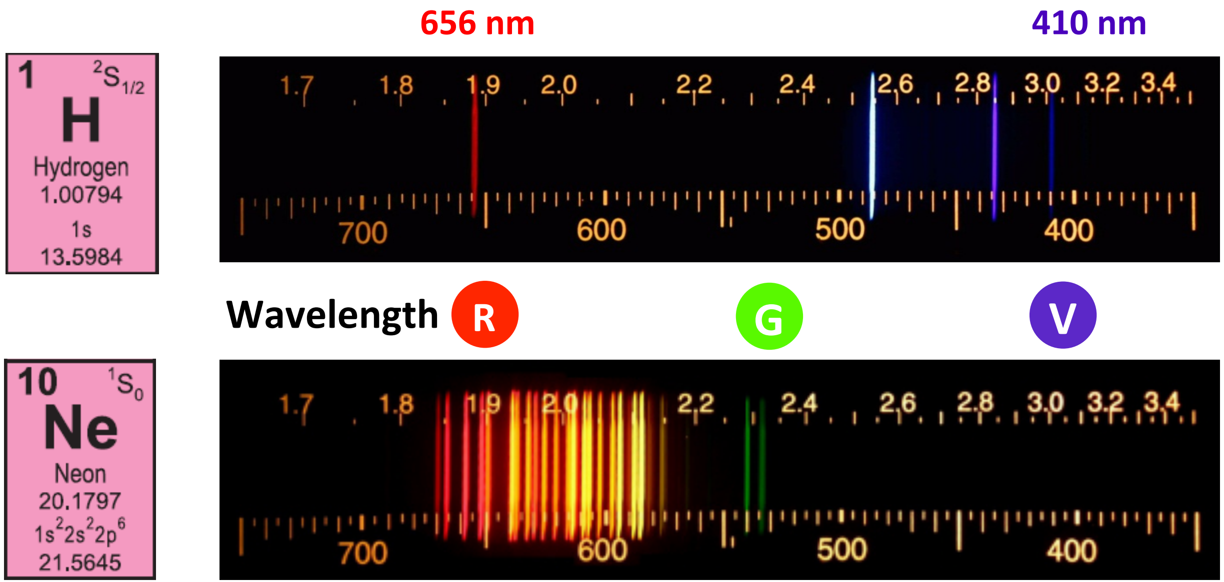

Emission spectra of gases often show sparse line structure – atoms only emit particular colors – evidence for “quantum” physics.

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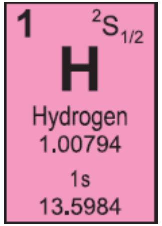
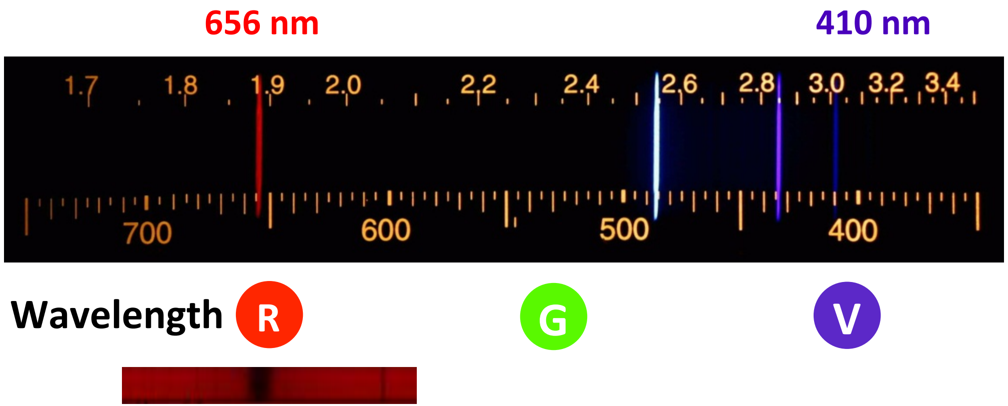
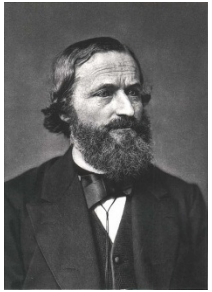




Robert Bunsen



Gustav Kirchhoff

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In 1859, Bunsen and Kirchhoff find that emission and absorption lines of gases occur at the same wavelengths. Thus Fraunhofer’s dark lines are attributed to absorption of sunlight by gases in the solar atmosphere.

The origin of atomic spectra remained a mystery until 1913.