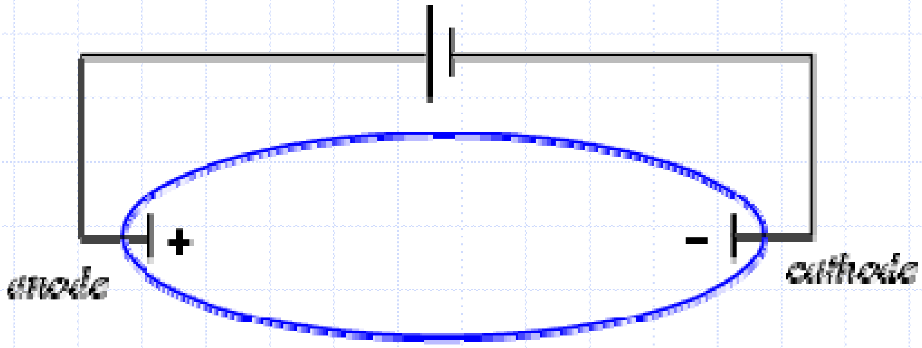
Quantization

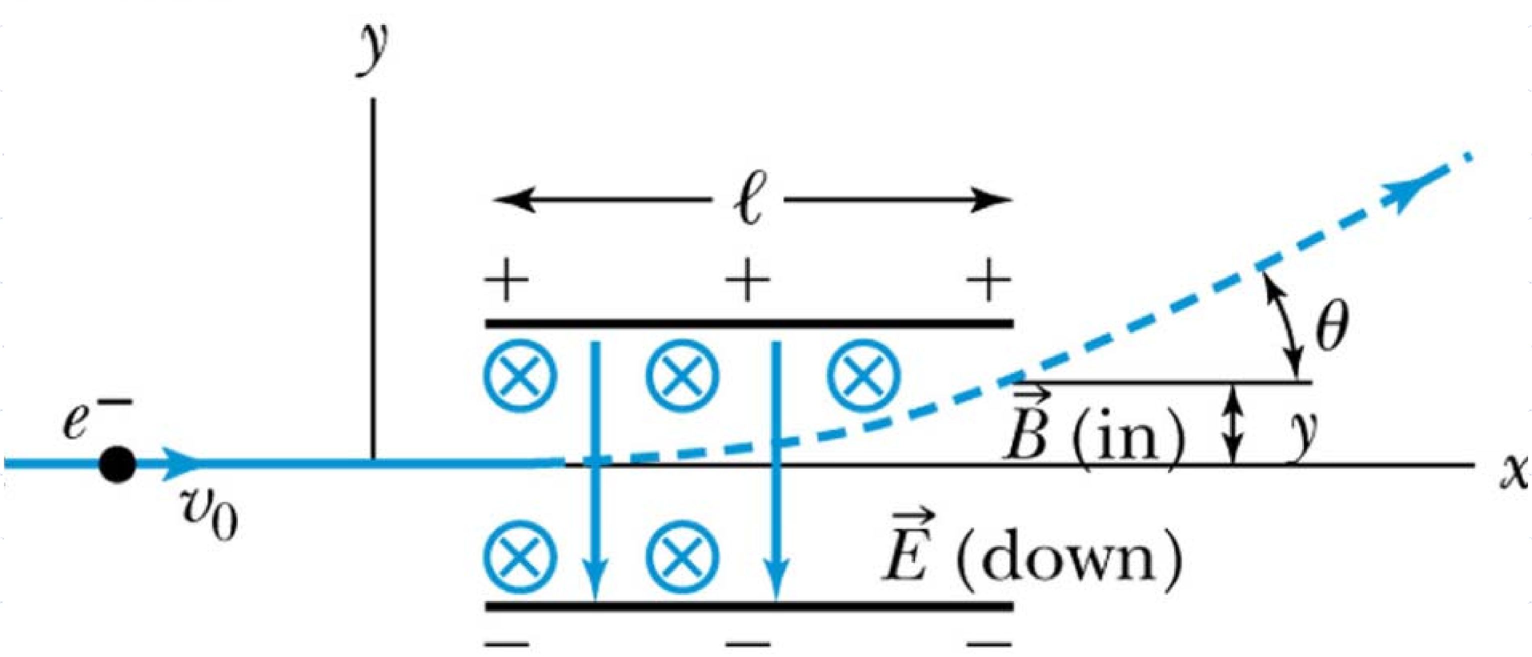
- In spite of the many successes of classical physics, experiments began to discover phenomena that were difficult to understand

Electron e/m

- Cathode ray tube



Electron e/m



Electron e/m

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) = 0$$

$$qE = qvB$$

$$v_x = \frac{E}{B}$$

$$\text{for } B = 0, F = qE$$

$$\tan\theta = \frac{v_y}{v_x} = \frac{a_y t}{v_x} = \frac{qE\ell}{mv_x^2}$$

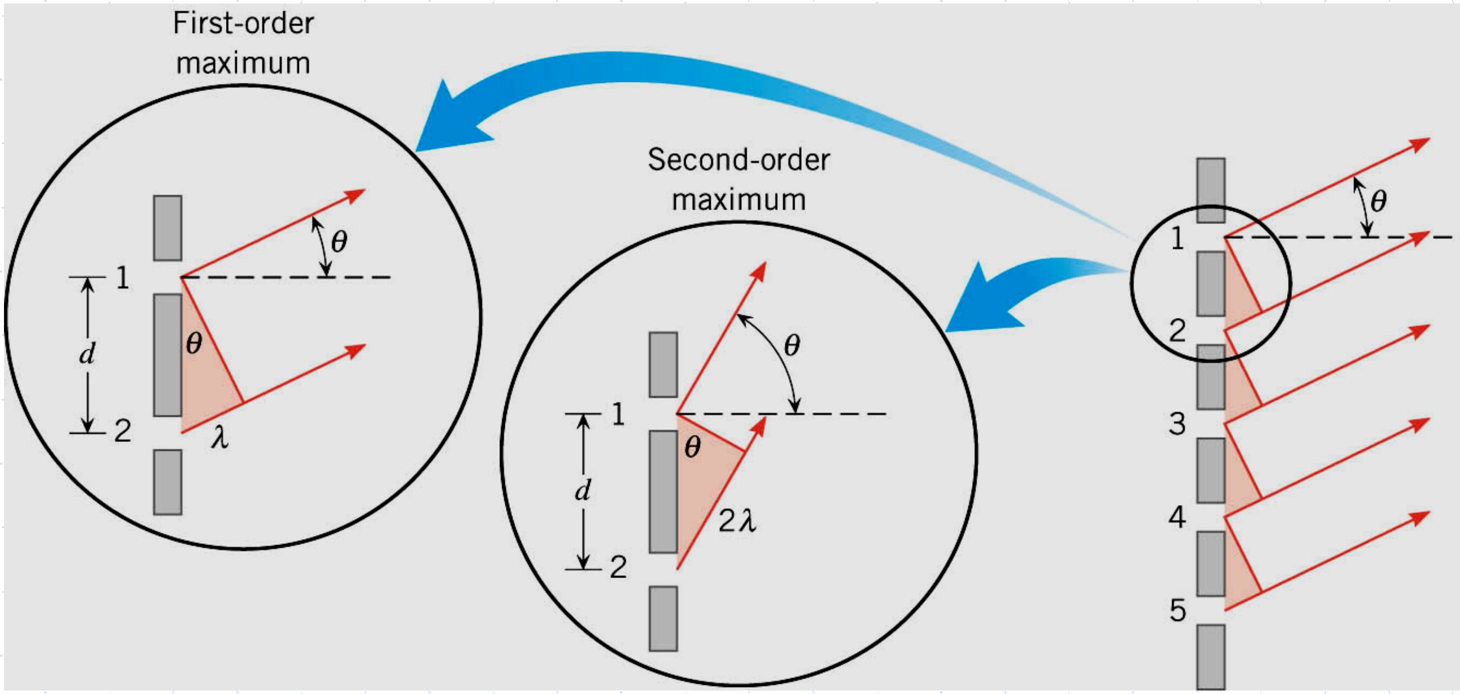
$$\text{thus } \frac{q}{m} = \frac{E\tan\theta}{B^2\ell}$$

Electron e/m

- This experiment established the electron as a particle
- The present value of e/m is
  - $e/m = 1.76 \times 10^{11}$ C/kg

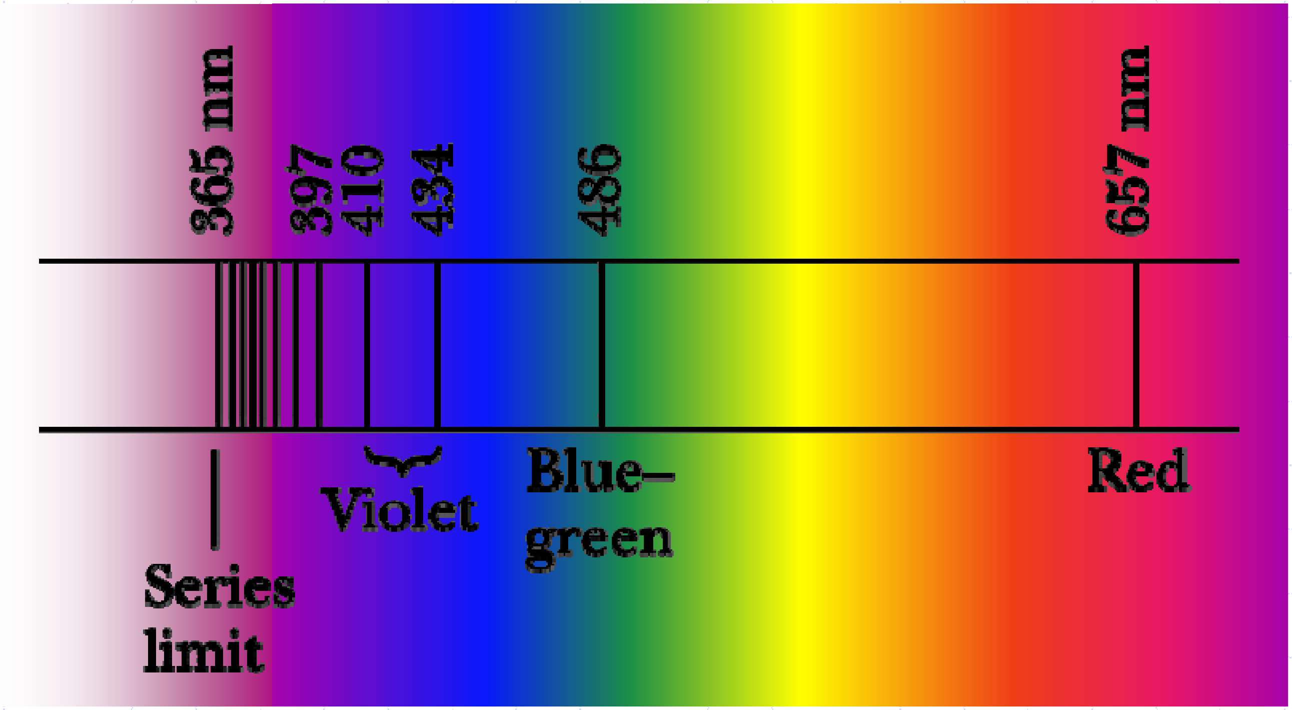
Line Spectra

- Recall from optics how a diffraction grating works



$$d \sin\theta = m\lambda$$

Line Spectra



$$\lambda = 354.56 \frac{k^2}{k^2 - 4} nm \quad \text{(Balmer series)}$$

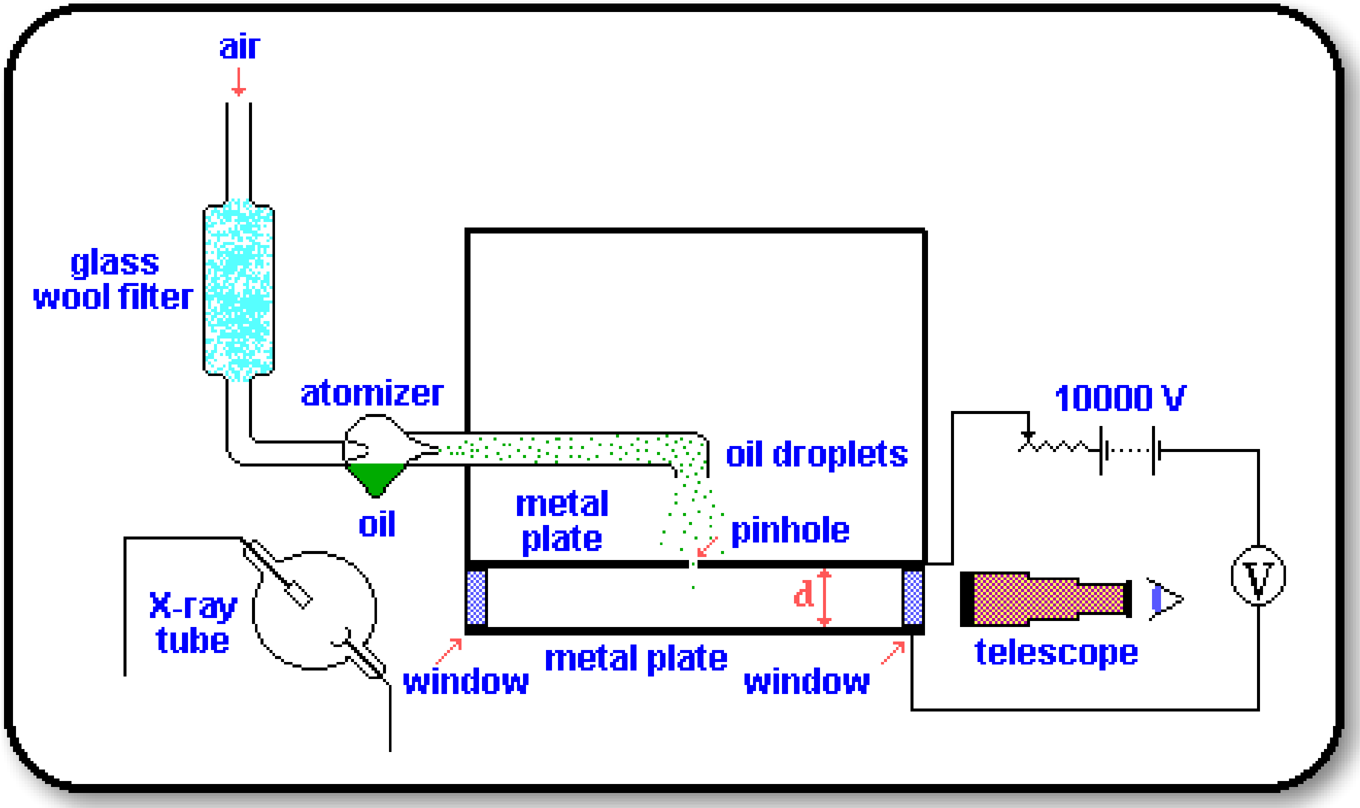
Line Spectra

Hydrogen Series of Spectral Lines

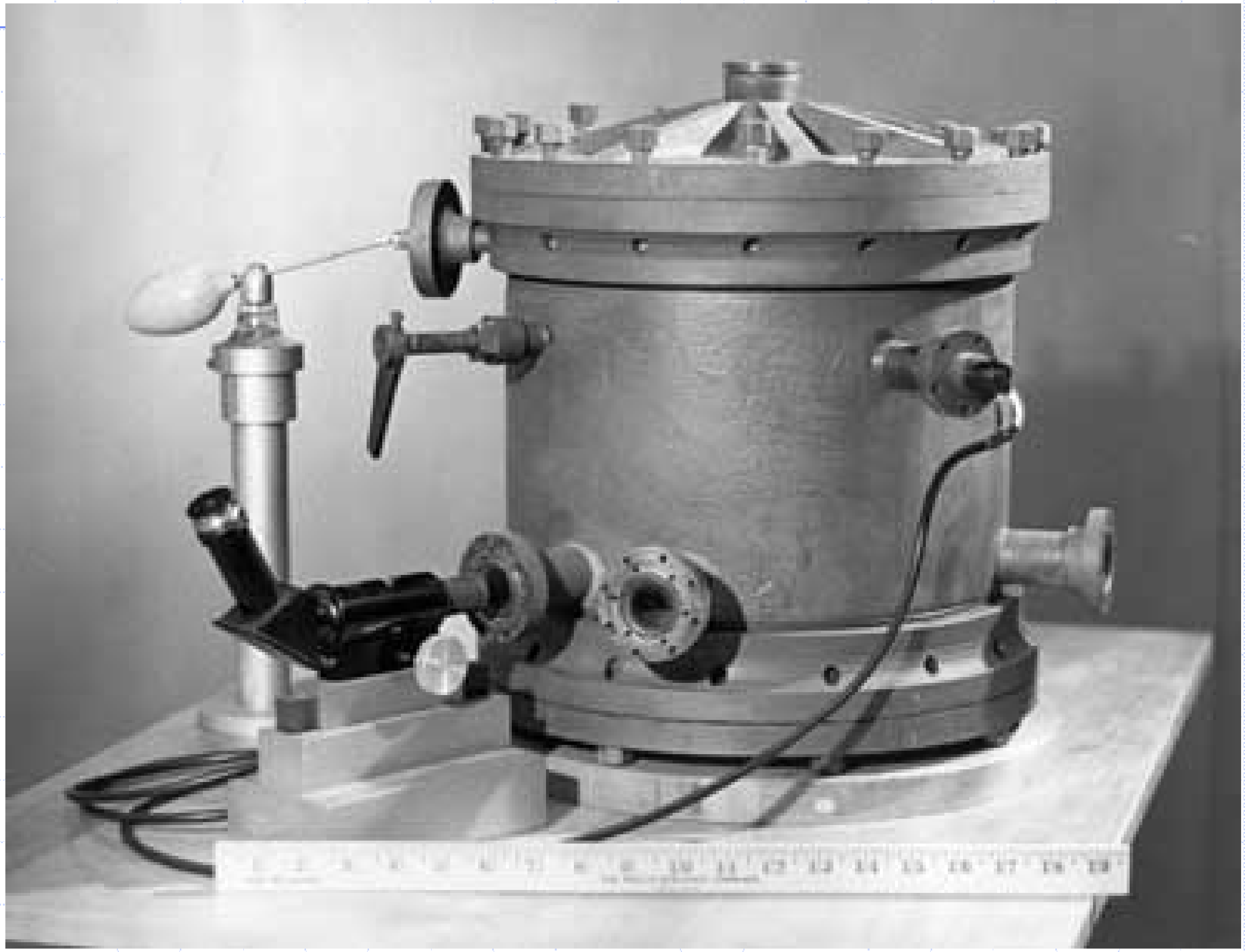
Discoverer (year)	Wavelength	*n*	*k*
Lyman (1916)	Ultraviolet	1	>1
Balmer (1885)	Visible, ultraviolet	2	>2
Paschen (1908)	Infrared	3	>3
Brackett (1922)	Infrared	4	>4
Pfund (1924)	Infrared	5	>5

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n^2} - \frac{1}{k^2}\right), \quad R_H = 1.096776 m^{-1}$$

Charge Quantization



Charge Quantization



Charge Quantization

- The oil drop experiences a downward gravitational force (mg) and an upward frictional force (bv)
- The terminal velocity of the falling oil drop is

$$-mg + bv = m\frac{dv}{dt}$$

$$v_f = \frac{mg}{b} \text{ for } \frac{dv}{dt} = 0$$

- The viscous force is given by Stokes' law with

$$b = 6\pi\eta r$$

- The mass is given by

$$m = \frac{4}{3}\pi r^3 \rho$$

Charge Quantization

- With the addition of an electric field we have

$$q_n E - mg - bv = m\frac{dv}{dt}$$

- The terminal velocity for rising is just

$$v_r = \frac{q_n E - mg}{b}$$

- And thus

$$q_n = \frac{mg}{Ev_f}\left(v_f + v_r\right)$$

Charge Quantization

- Millikan observed that the charge on the drops was always ne where n is an integer
- The present value of e is 1.602×10^{-19}C

Charge Quantization

- Millikan's measurement was not without controversy
  - Some charge he only used the "best" data
    - *This is almost exactly right & the best one I ever had!!!*
    - *Exactly right*
    - *Publish this Beautiful one*
    - *Error high will not use*
    - *Too high by 1½%*
  - His graduate student came up with the idea of using oil (but was not co-author on the paper)