Diffraction Grating And Emission Spectra

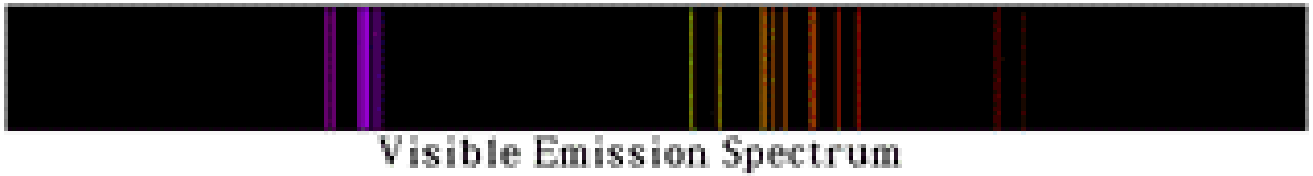
To determine the wavelengths emitted by the atomic element in a discharge tube and to identify the element

Introduction

Excitation of atoms (most often gaseous matter) ⇨ light emission

First quantitative observation of emitted light with a prism

Find: sharp lines of different colours ⇨ emission spectrum



Study of atomic spectra ⇔ Quantum theory of matter

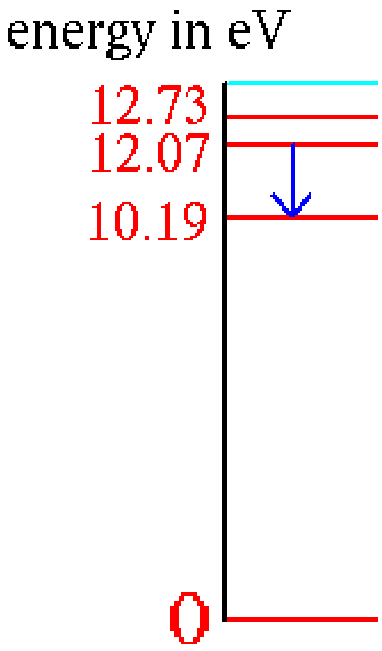
Experimental improvements ⇔ diffraction grating

grating spectrometer

The spectrometer used for precise wavelength measurements

This experiment: calibrate grating spectrometer ⇨ measure the atomic spectrum ⇨ identify the element

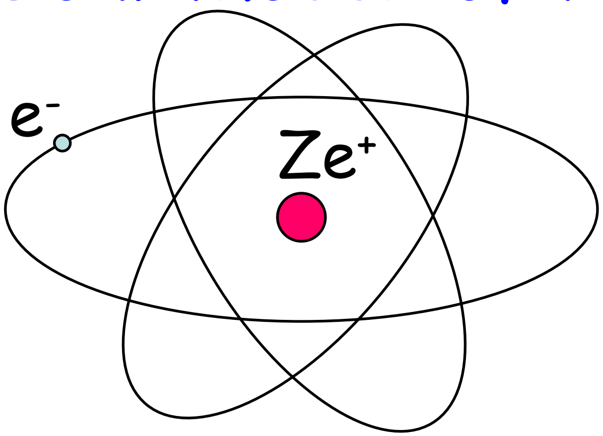
Atomic Theory:



photon emission

- Quantum theory: electrons in atoms at discrete energy levels

- The "Bohr Model" of the atom

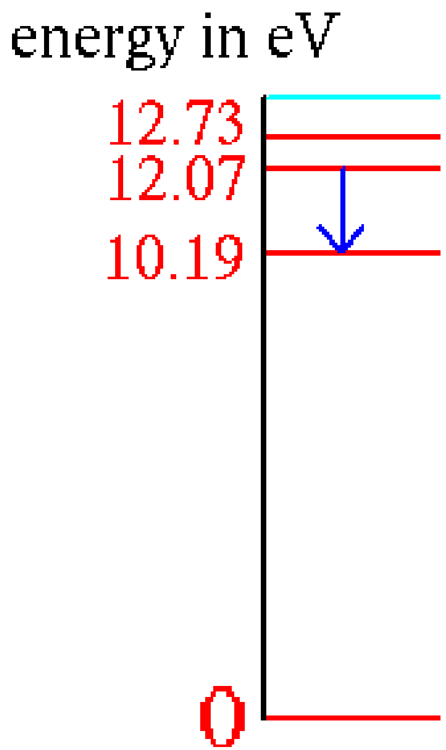


- Electrons at excited states return to lower energy states with emission of light quanta of distinct energies

Niels Bohr

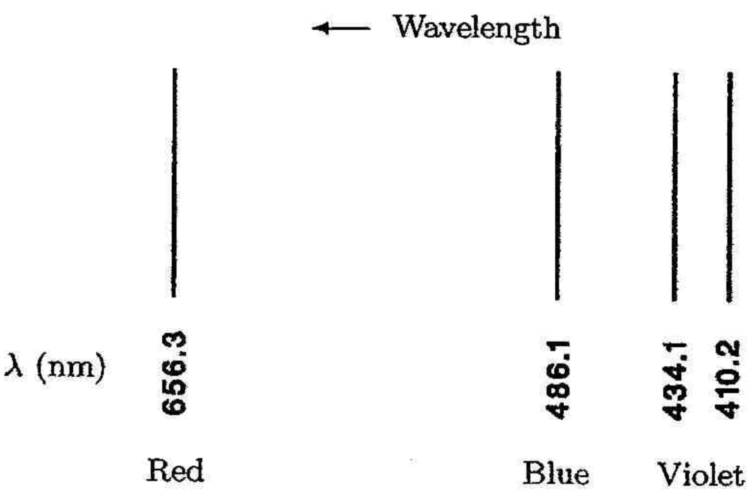
Atomic Theory:

Quantum theory: prediction of the energy levels



photon emission

The energy, or wavelength of each photon determined by the energy difference between states of the atom

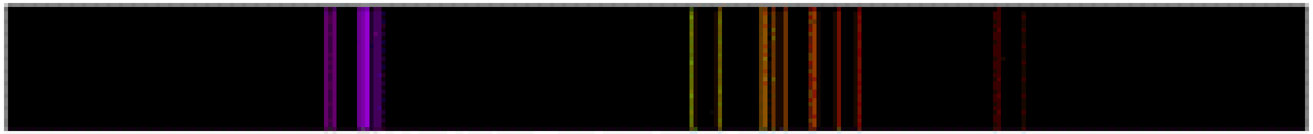


Hydrogen atom

Characteristic for each atom → well defined spectrum of wavelengths from the energy states

The spectrum → identification of the element

Identification procedure: measurement of the wavelengths of as many lines in its spectrum as possible and look up in a table of prominent lines



Visible Emission Spectrum

Theory of the Diffraction Grating

Collimated (parallel) monochromatic light past a narrow slit → a pattern of maxima and minima in intensity on a screen

The pattern → fringes of diffraction pattern

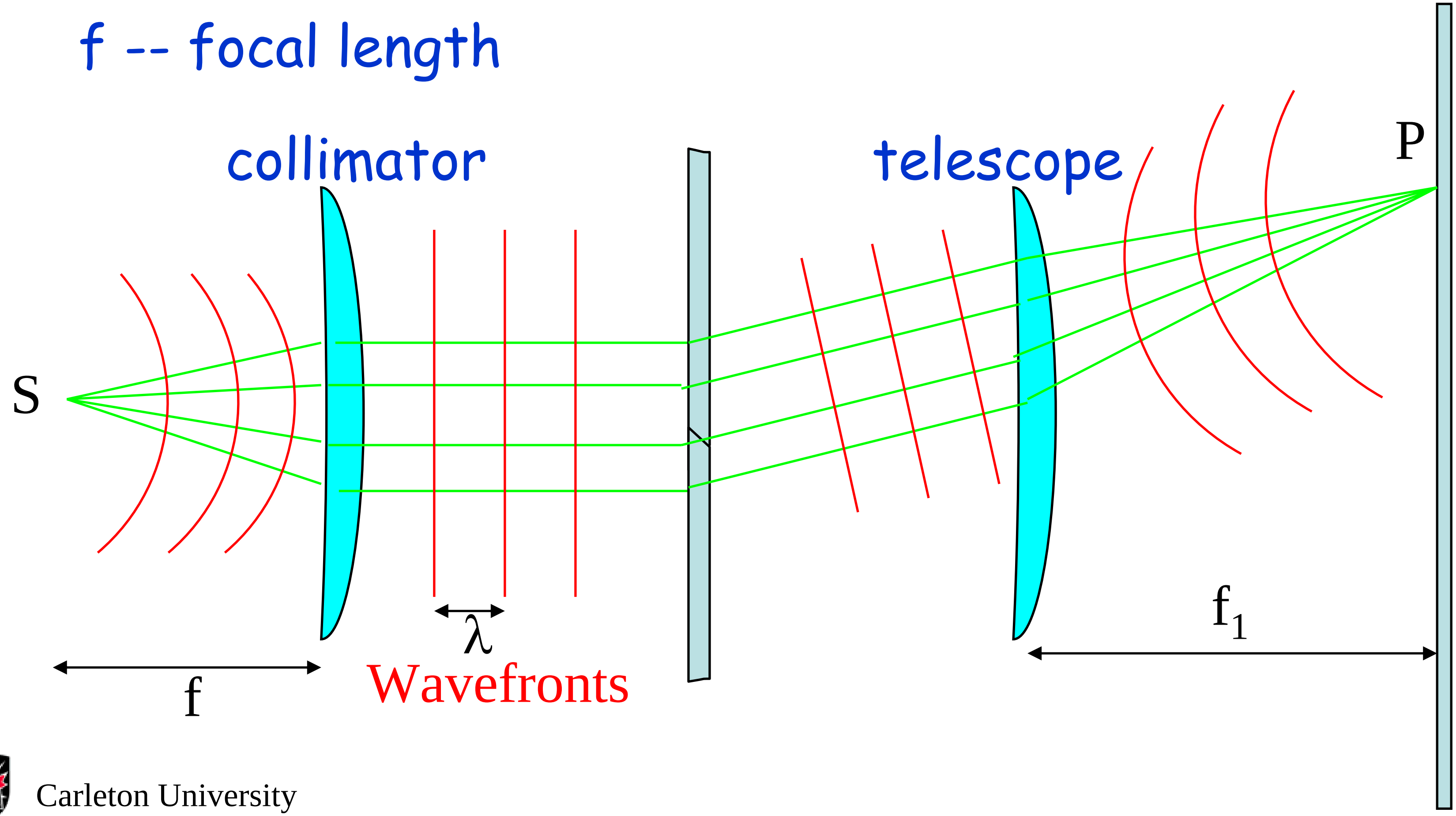
Large number of evenly spaced slits → narrow bright fringes

Wide dark spaces (minima) between the fringes

A diffraction grating → a flat plate with a large number of uniform slits scribed at regular intervals

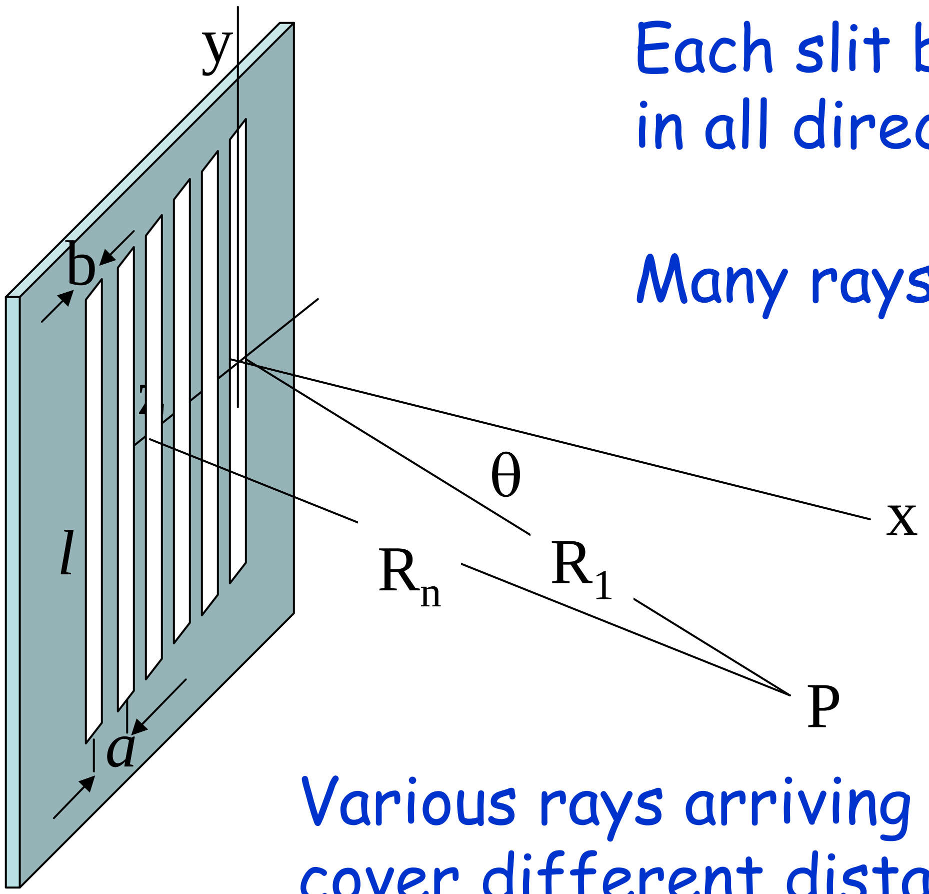
Practical arrangement:

f -- focal length



Each slit becomes a radiator of waves in all directions.

Many rays spread out from the grating



Various rays arriving at a point P on a screen cover different distances from a slit

The difference between any two lengths to the same screen → path difference

The path difference = $n\lambda$ → the sine waves in phase and the intensities add up to produce a bright fringe

The difference is $\frac{1}{2}\lambda$, $3/2\ \lambda$, $5/2\lambda$, … → the waves 180^0 out of phase give a dark spot or line

Rays diffracted by θ → path difference = $d \sin \theta$

Thus for a maximum

$$n\lambda = d\sin\theta$$

aka. **the grating equation**

n = 1, 2, … are the 1^{st}, 2^{nd}, etc orders

λ = wavelength of the line

d = grating space *i.e.*, distance between successive slits

θ = off axis angle measured from the straight through

Set $1/d = N$ = number of slits per cm → the grating eq^n

$$\sin\theta = nN\lambda$$

Apparatus

The spectrometer is made up of three parts:

the collimator – an optical device which produces a parallel beam of light from your monochromatic light source

the telescope – an optical device which focuses a beam of parallel light in the plane of the crosshairs

the turntable – supports the diffraction grating and enables measurement of the angular position of the telescope

DO NOT TOUCH THE RULED SURFACE OF THE GRATING

Part I: Procedure

- Using the sodium light position the crosshair on the first order spectrum on each side of the "straight through"

- Read one scale and vernier and record these θ_{left} , θ_{right} readings (1^0 = 60′)

- Repeat for the second order spectrum

- With careful adjustments and a narrow slit readings for both sodium lines are possible, particularly in the second order where the separation is greater.

Using the Data

- For the first order: $\sin\theta = N\lambda$
- For the second order: $\sin\theta = 2N\lambda$

where N = number of lines per cm of the grating
θ = angle of deviation
λ = wavelength of the light used

- Calculate the deviation for each line in each order

$$\theta = |\theta_{\text{left}} - \theta_{\text{right}}|/2$$

- Use the known wavelengths of the sodium lines and calculate the value of N in lines per cm for the grating

- Average your result
(This should be close to 5,900 lines/cm)

Part II: Procedure

- Replace the sodium light with the unknown light, letting the former cool down before you handle it

- Measure the angles for about six lines in the first and second order

- Calculate the wavelengths using the value of N determined from the sodium measurements

- Identify the element producing the radiation comparing read out λ's with the tables

Wavelength	Element	Wavelength	Element	Wavelength	Element	Wavelength	Element
671.7	Ne	607.1	Rb	515.6	Cd	450.1	Xe
667.8	He, Ne	603.0	Ne	508.6	Cd	447.2	He
659.9	Ne	598.2	Ne	504.8	He	446.4	Kr
656.3	H	594.5	Ne	501.6	He	441.4	Cd
653.2	Ne	589.4	Zn	495.8	Fe	438.8	He
650.6	Ne	588.2	Ne	492.3	Xe	438.4	Fe
645.6	Kr	587.6	He	492.2	He	436.3	Kr
643.8	Cd	587.1	Kr	491.6	Hg	435.8	Hg
641.0	Ne	586.9	Ne	486.1	H	434.0	H
638.3	Ne	579.0	Hg	482.9	Xe	432.0	Kr
636.2	Zn	577.0	Hg	481.0	Zn	430.8	Fe
633.4	Ne	572.4	Rb	480.0	Cd	427.4	Kr
630.5	Ne	564.8	Rb	473.4	Xe	421.6	Rb
629.8	Rb	557.0	Kr	472.2	Zn	420.2	Rb
626.6	Ne	556.2	Kr	471.3	He	412.2	He
621.4	Ne	546.1	Hg	468.0	Zn	410.1	H
620.6	Rb	543.1	Rb	467.8	Cd	407.8	Hg
616.4	Ne	536.3	Rb	467.1	Xe	406.2	He
616.0	Rb	527.0	Fe	466.8	Fe	404.7	Hg
614.3	Ne	526.0	Rb	463.0	Zn		
609.6	Ne	518.2	Zn	462.4	Xe		
607.4	Ne	516.9	Fe	450.2	Kr		

All wavelengths in nm

To adjust the telescope:

(a) Point the telescope at a light coloured surface and move the the eyepiece in and out until you can see the crosshairs clearly and without straining your eyes. Turn the eyepiece if necessary so that the crosshairs are vertical and horizontal

(b) Point the telescope at a very distant object and turn the focusing know until you see the image clearly and there is no parallax between the image and the crosshairs. You have now adjusted the telescope so that it will focus parallel light at the crosshairs

Do not change this focus

To adjust the collimator

(a) Place the source of monochromatic sodium light a few centimeters behind the slit of the collimator. Make sure that the slit is not closed

(b) Move the telescope around so that it is in line with the collimator. Look through the telescope and adjust its position until you can see the image of the slit through the eyepiece.

(c) Adjust the focusing know of the collimator until you see the image of the slit clearly in the telescope and there is no parallax between it and the crosshairs. You have now adjusted the collimator so that it is producing a beam of parallel light

Do Not change this setting

To adjust the turntable

The turntable must be level in order to be sure that your images will appear in the middle of the screen, not off at an angle where the telescope may not be able to pick them up;

x, y, and z are the three leveling screws under the turntable;

BC is the diffraction grating

(a) Place the diffraction grating on the turntable so the lines on the grating face the telescope

(b) Move the telescope until the first order diffraction lines are seen

(c) Adjust screw y until the image of the slit is equidistant from the top and bottom field of view

(d) Swing the telescope around until the first order lines are seen

(e) Adjust screw x until the image of the slit is equidistant from the top and bottom of the field of view.

(f) Check to see if the other lines are still in the middle of the field