Michael Kidger's Atomic Physics Notes

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Preface

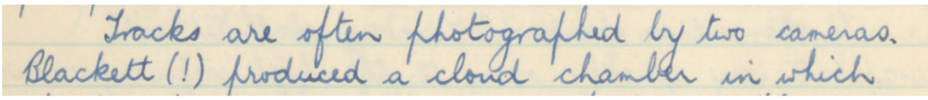
These beautiful notes on Atomic Physics written in the mid-1950s originate from another era. To appreciate all aspects of them, I think we need to take a step back to that period of time in England, particularly as regards education and universities.

In the mid-1950s, English society was even more stratified than at present. Only 4% of school leavers went to University, compared to more than 40% at present. So unlike now, going to University was indeed a privilege, and the subjects offered at University were almost all academic, as opposed to utilitarian. Imperial College London was arguably the top university for science and engineering whose students were selected solely on merit. Michael not only won admittance to the Physics Department at Imperial, but also did so with scholarships from his local county of Worcestershire. Like most of his contemporaries, Michael would have realized his good fortune and taken his studies very seriously.

The first thing that came to my mind when I saw these notes was: this is what we all did! We attended lectures and laboratory sessions each day, and then at night or on the weekend, we "wrote up the lectures", which frequently involved having a couple of textbooks in front of us to help us make sense of the subject. The more diligent students did this for every course, the rest of us for a few courses that we really enjoyed or thought might be more important. We did this as a way of trying to understand the material: writing "your own" notes is a step on the way to teaching the subject matter, which is when you find out if you really understand it. Michael, not surprisingly, turned out to be a brilliant and exceptionally clear teacher as well.

If "writing up the lectures" was part and parcel of being a student at this time, it does not mean that we all did a great job. I have some of my old notes from the mid-1960s, and they are an embarrassment; a barely legible scrawl that frequently showed I also had little understanding for the topic! In contrast, these notes by Michael are not only beautifully written but demonstrate that he had a good understanding of the topic. They are a visual feast: legible, cursive writing using a fountain pen and no crossings-out! That requires concentration, attention to detail, and a focused mind. It's no coincidence, in my opinion, that these same attributes are required in optical design.

We do not know the exact circumstances in which Michael prepared these lecture notes: we do not know who the lecturer was, or what textbooks he used to supplement the lecture material. As Michael painstakingly wrote these notes, did his mind drift at any point, perhaps laterally to related topics in physics… or perhaps to cricket? There are small human touches that an ex-Imperial person like myself can recognize. For example, on page 8, Michael writes:



What is the significance of the exclamation mark(!)? It turns out that Patrick Blackett, Nobel Laureate, had joined Imperial as the Head of the Physics Department in 1953, and every undergraduate student would have been in awe of him. Such were Blackett's achievements at Imperial itself that the Physics Department was re-named The Blackett Laboratory in 1975, the occasion being marked by the then Prime Minister, Harold Wilson, giving a 30 minute talk on Blackett's life in the main physics lecture theatre (indeed another era, can you imagine any current Prime Minister or President being capable of this?).

As for the physics content of the notes, physics and the teaching of physics, like all science, moves with the times. This is Atomic Physics as it was in the 1950s, and these notes, as a snapshot of the time, are a record of how the subject was taught then. A present-day Atomic Physics course would be less historical and focus on atomic structure with a greater emphasis on wave functions, spin-orbit interactions, and nuclear effects. Optical spectroscopy, and in particular high-resolution laser spectroscopy, has played a huge role in our understanding of atoms.

Tina Kidger and SPIE Press have done the community a great service by archiving these historical notes for the benefit of present and future generations.

Chris Dainty
Galway, June 2024

M. J. Kidger,
Royal College of Science

Atomic Physics.

1/. The Conduction of Electricity through gases.

Introduction.

1803 - Dalton - matter is atomic in nature
1813 - Prout - atoms built up of hydrogen atoms.
Sir J.J. Thomson - discovery of electron, particle with negative charge and mass 1/2000 that of hydrogen atom.
Rutherford - massive small nucleus with light electrons revolving around
Some nuclei are unstable - radioactivity.
Planck's quantum theory - radiation is also atomic

The Electrical Conductivity of Gases.

Wilson -1900- Gold leaf electroscope slowly discharges in air.

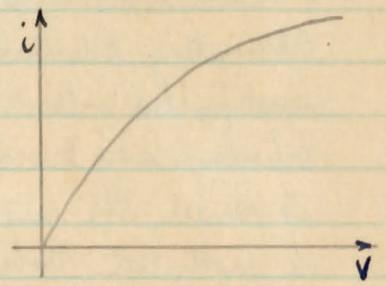
Combustion gases from flames are conducting; so are gases which are irradiated by u-v light or X-rays.

Conductivity is due to charged particles in the gas.

Particles are negative and positive ions.

Variation of Current with applied voltage.

Current through an ionised gas does not obey Ohm's law, but reaches a 'saturation current'.

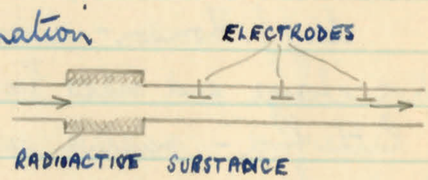


Recombination of Ions.

Even when no current flows, the ions recombine, eventually reaching a steady state. Number of ions rises in an exponential manner. [$n = \frac{n_0}{(1+n_0 \alpha t)}$ - rate of decrease.]

α = coefficient of recombination

α measured by Rutherford. Ionisation at three points was measured.

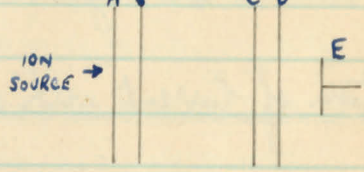


Hence α is found. Purity and turbulence are difficulties. More accurate methods evolved since; these require a knowledge of velocities in of ions.

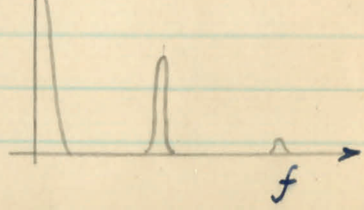
The Mobilities of Ions.

Acceleration of gaseous ions = $\frac{Xe}{m}$. After time t, ion is brought to rest by a molecule. Process is repeated. Mean drift velocity = $\frac{Xet}{2m} = kX$. k is known as ionic mobility. Measured in 1897 by Rutherford.

Tyndall's method:
A, B, C, D are sheets of gauze.
E is connected to electrometer.



Alternating potential applied between A and B. Bursts of ions pulled into BC. Alternating potential also applied between C and D. As frequency is varied, the curve shown is produced. Mobility is calculated from distance



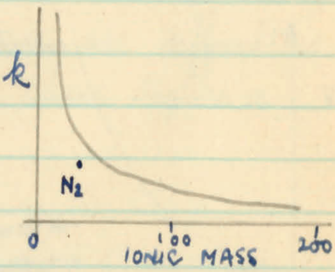
The Effect of Ionic Mass on Mobility

We are now concerned with unclustered ions.

IONS	GAS			
	He	Ne	N_2	H_2O
Li^+	25·8	11·8	4·2	0·73
Na^+	24·2	8·7	3·0	0·72
K^+	22·9	7·2	2·7	0·71
Rb^+	21·4	6·5	2·4	0·70

Mobilities measured in cm^2/sec volt at 760 mm. Hg and 18 °C.

Mobility falls with ionic mass. Nitrogen is carrier gas. Only deviations are shown by nitrogen ions.



The relation between mass and mobility.

1905 - Langevin - theory gives $k \propto \sqrt{(1 + m/M)}$

M = mass of ion   m = mass of molecule.

Formula is only approximate.

Suppose   i   ii

Ions move in own gas M = m   mass of cluster $M \gg m$

∴ Ratio of mobilities $= \sqrt{2}$. This is obeyed to a first order of approximation.

The effect of pressure and temperature.

$v = kX/p$ on simple theory, assuming v is small compared with thermal velocities. As v increases, formula breaks down. Empirically, $v = k(X/p) + k'(X/p)^2$.

Tyndall - 80°-500°K $k = BT^{1/2}/(C+T)$ - empirically.

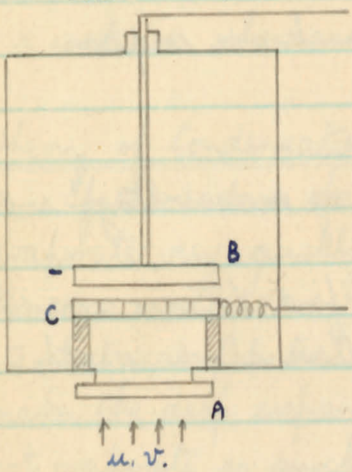
The Effect of Polar impurities.

Rate of growth of cluster with, say water vapour, is large at first. Saturation is soon reached. Number of molecules in a cluster is about 4-17.

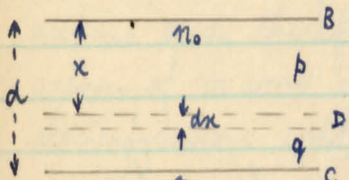
Ionisation by Collision.

As the voltage across a gas increases, saturation is passed and breakdown occurs with a spark. When an ion collides with a molecule, the molecule is ionised if the voltage is high. A pair of electron ions is formed, and so on.

Townsend:



A is quartz window
B is zinc plate
C is quartz slab covered with a silver layer having scratches on it.
Electrons are emitted at B



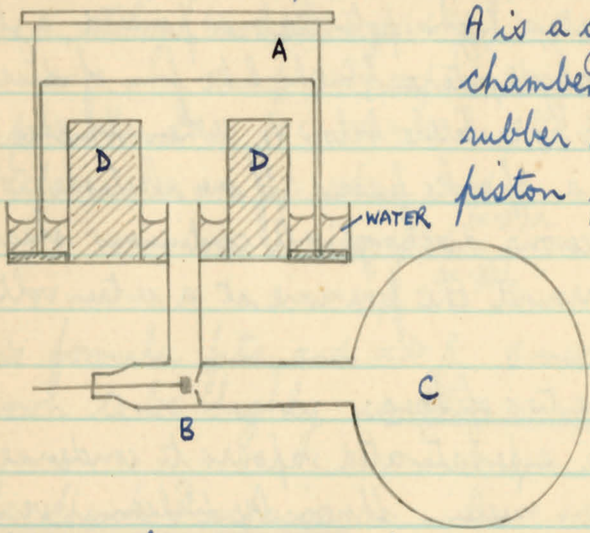
n_0 ions/sec at B. Each ion (−ve) produces α ions/cm. Each +ve ion produces β ions/cm.
Let p be the number of ion pairs generated/sec. between B and D.
No of − ions passing thro D $= (n_0 + p)$/sec
" " + " " " D $= q$ /sec

Number of pairs of ions created/sec in dx is

$$dp = (n_0 + p)\alpha dx + q\beta dx$$

$$n = n_0 + p + q \quad \therefore q = n - n_0 - p$$

The Wilson Cloud Expansion Chamber.

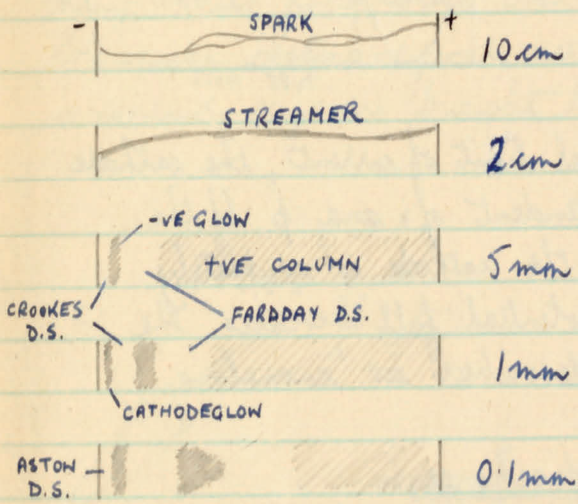


A is a cylindrical glass chamber standing on a rubber disc. A moveable piston produces the expansion in A. D are blocks of wood. C is a large evacuated flask. B is a valve. When B is opened, the air under the piston is connected to C and the piston drops suddenly producing an adiabatic expansion in A. Dust particles are first precipitated out.

Tracks are often photographed by two cameras. Blackett (!) produced a cloud chamber in which the particle acts as a tigger. Fuller details later. The exposure must be made soon after the expansion

2. Electric Discharge through Gases at Low Pressures.

Appearance at Low Pressures.

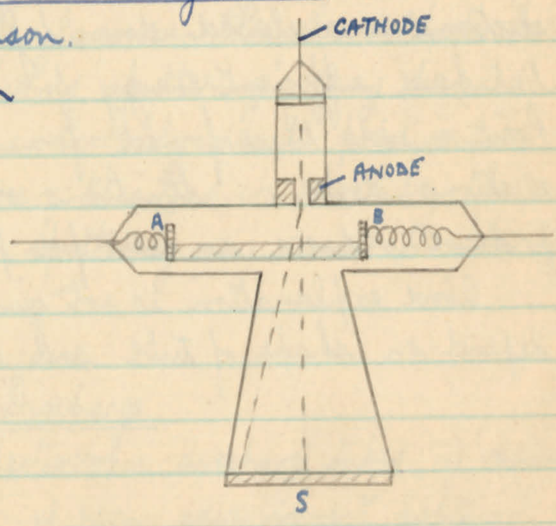


Striations are formed in positive column at about 1mm. When pressure is lower still, Crookes d.s. fills the whole tube and the electrical resistance suddenly increases. Cathode is now emitting cathode rays which cause fluorescence.

Sir J.J. Thomson showed that cathode rays are electrons. The electrons cause a target to emit X-rays.

Potential variations in the discharge tube.

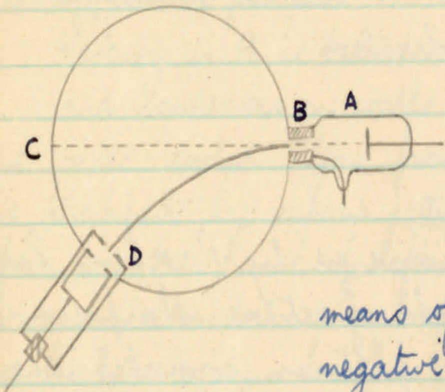
measured by J.J. Thomson.



Discharge passes between A and B. Deflection of cathode rays on screen S gives a measure of the field. A and B can be moved across, and hence the field distribution can be studied.

Cathode Rays.

When p is very low, greenish fluorescence appears. Caused by beam of radiation, which is known to be electrons. Many bodies phosphoresce when hit by cathode rays. Potassium platino-cyanide used on screens. If the cathode is concave, rays are brought to a focus. Rays may heat and even melt platinum.



Perrin - 1895

Cathode rays produced by A. Fine beam selected by B. Green spot on C. Spot may be deflected to D by means of magnetic field. D collects negative charge, showing that electrons are negative. Cathode rays may also blacken a photographic plate.

Cathode Sputtering.

After some time the glass near the ~~ele~~ cathode becomes covered with metal. This is 'sputtering'. May be used to give uniform thin films. Probably due to positive ion bombardment. The heavier the gas in the tube, the more effective is the action. Sputtering may cause trouble if it is unwanted.

Types of Low Pressure Discharge.

i) X-ray tubes, ii) spectroscopic discharge tubes, iii) 'vacuum' rectifiers, iv) oscillographs, v) neon advertisement lighting.

5.1 The Quantum Theory.

Difficulties with the Classical Theory of Radiation.

Classical theory can be applied to black-body radiation. Energy is emitted on continuously variable wavelength. Rayleigh and Jeans found radiant energy between λ and $\lambda - d\lambda$ on classical theory.

Jeans - radiation broken up into monochromatic wave trains. No of such trains between λ and $\lambda - d\lambda$ is determined.

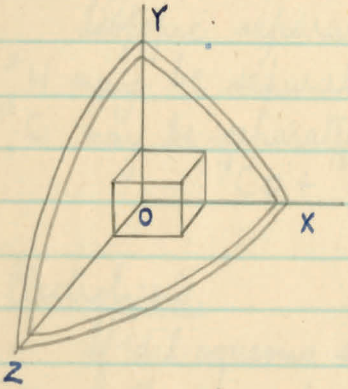
Suppose radiation of λ forms steady stationary waves by being enclosed between 2 walls with separation x.
$\therefore x = n\lambda/2$, where n is an integer. Consider a cubical box of side a.

$$\therefore la = n_1\lambda/2,\ ma = n_2\lambda/2,\ na = n_3\lambda/2.$$

n_1, n_2, n_3 are integers; l, m, n are direction cosines in radiation direction.

$$a^2(l^2+m^2+n^2) = (n_1^2+n_2^2+n_3^2)\lambda^2/4$$

$$\therefore \nu = (n_1^2+n_2^2+n_3^2)^{1/2}\ c/2a$$



Number of ~~freque~~ possible stationary vibrations between ν and $\nu + d\nu$ can now be found.
$n_1 c/2a$, $n_2 c/2a$, $n_3 c/2a$ are x, y, z coordinates. This gives cubic lattice, where distance from the origin is equal to ν. The total no. of combinations of n values such that

$$\nu < (n_1^2+n_2^2+n_3^2)^{\frac{1}{2}} \frac{c}{2a} < \nu+d\nu$$

is the number of points in one octant between spheres of radius ν and $\nu+d\nu$. Volume is $4\pi\nu^2 d\nu/8$. Total number of vibrations in the cube of volume a^3 is

$$4\pi\nu^2 d\nu / 8 (c/2a)^3$$

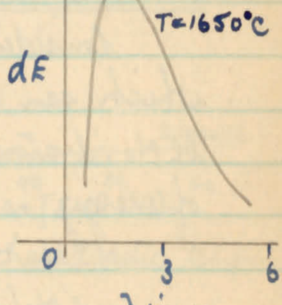
No / unit volume is $\therefore 4\pi\nu^2 d\nu/c^2$ — forgetting polarisation.
Waves with $\perp$ ar modes of vibration should be counted as 2.

$\therefore$ No / unit volume is $8\pi\nu^2 d\nu / c^2$

Energy $dE = 8\pi\nu^2 d\nu \, kT/c^2 = 8\pi kT\lambda^{-4} d\lambda$. This is the Rayleigh-Jeans classical radiation formula.

This is wrong, since it gives $E = \int_0^\infty 8\pi kT\lambda^{-4} d\lambda = \infty$

Correct relation is found experimentally by Lummer and Pringsheim (1897), using radiation bolometer.



Stefan-Boltzmann law: $E \propto T^4$ is confirmed

Fundamental assumions in Rayleigh-Jeans formula must be at fault.

<u>Difficulties with the classical theory of specific heats.</u>

Kinetic theory: mean kinetic energy of each deg. of freedom of a gas molecule is $kT/2$. $\therefore$ Total mean energy $= 3kT/2$. $\therefore$ Total mean kinetic energy for 1 gm. mol $= 3kTN/2 = 3RT/2$. Total energy $= E = \overline{k.e.} + \overline{p.e.} = 2\,\overline{k.e.} = 3RT$ $\therefore (\delta E/\delta T)_v = 3R = 5{\cdot}96$ cal./gm mol)

Heavy elements are roughly right, but it fails completely for light atoms like carbon, and it also fails at low temperatures. Classical assumptions must be at fault.

The Quantum Theory.

1900 - Planck made four basic assumptions:

(1) a black body contains simple harmonic oscillators which can vibrate with all possible frequencies.

(2) frequency radiated by an oscillator = frequency of kinetic motion.

(3) Radiation is emitted at separate intervals, the amplitude remaining constant in the intervening periods.

(4) An oscillator emitting ν can only radiate in units, or quanta, of $h\nu$, where h is a universal constant. (Planck's const)

The Quantum Theory of heat radiation.

Consider a black body radiator with linear oscillators which can only emit energy $0, h\nu, 2h\nu, 3h\nu, \dots$. Let there be N_0 vibrators with $E=0$. From kinetic theory of equipartition of energy, no with $E=\mathcal{E}$ is $N_0 e^{-\mathcal{E}/KT}$.

$$N = N_0 + N_0 e^{-x} + N_0 e^{-2x} + N_0 e^{-3x} \dots\dots N_0 e^{-nx} \dots \qquad \left(n = \frac{h\nu}{KT}\right)$$

$$= N_0(1 + e^{-x} + e^{-2x} + e^{-3x} \dots\dots + e^{-nx} \dots) = N_0/(1-e^{-x})$$

Total energy of $N_0 e^{-x}$ resonators is $h\nu . N_0 e^{-x}$

Total energy $= 0.N_0 + h\nu N_0 e^{-x} + 2h\nu N_0 e^{-2x} \dots nh\nu N_0 e^{-nx} \dots = E$

$$E = h\nu . N_0 e^{-x}(1 + 2e^{-x} + 3e^{-2x} \dots\dots ne^{-(n-1)x} \dots)$$

$$= h\nu N_0 e^{-x}(1-e^{-x})^{-2} = h\nu N e^{-x}(1-e^{-x})^{-1}$$

$$= h\nu N/(e^{x}-1) = h\nu N/(e^{h\nu/KT}-1)$$

$\therefore$ Average energy / resonator of frequency ν is $E' = h\nu/(e^{h\nu/KT}-1)$

Energy / resonator must be multiplied by no of resonating modes of that frequency / unit volume. $(= 8\pi\lambda^{-4}d\lambda)$

$$\therefore dE = 8\pi\lambda^{-4}d\lambda \; h\nu \,(e^{h\nu/KT}-1)^{-1}$$

$$= 8\pi hc\lambda^{-5}d\lambda/(e^{hc/K\lambda T}-1)$$

can only move in certain orbits (quantised orbits)

<u>Bohr's Theory of the Hydrogen Spectrum.</u>

Two fundamental postulates:-

(1) Stationary states exist in which the electron can rotate without radiating.

(2) A quantum of radiation is emitted when the electron jumps from one orbit to another. If energy in first state is E_2, in second state E_1, then $h\nu = E_2 - E_1$. This is Bohr's frequency condition.

$\nu' = \frac{E_2}{hc} - \frac{E_1}{hc}$ - difference between 2 terms.

For equilibrium, $Ze.e/r^2 = mv^2/r$ ⓐ $\therefore r = Ze^2/mv^2$

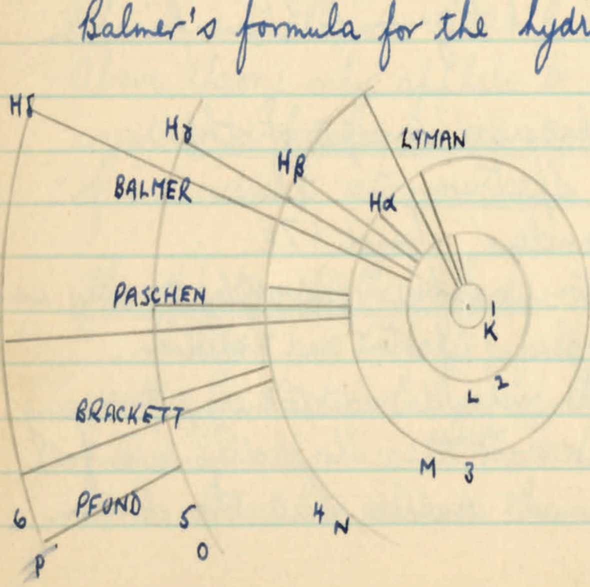
If P.E. is 0 when $r = \infty$, then P.E. is $-Ze^2/r$ when $r = r$.

$\therefore$ Total energy $E = \frac{1}{2}mv^2 - Ze^2/r = \frac{1}{2}\frac{Ze^2}{r} = -\frac{1}{2}mv^2$

Bohr now assumes that in the possible orbits, the angular momentum is quantised, ie $= n\frac{h}{2\pi} = mvr$ ⓑ.

$\therefore$ From ⓐ and ⓑ, $v = 2\pi Ze^2/nh$, $E = -2\pi^2 Z^2 e^4 m/n^2h^2$

$\therefore E_2 - E_1 = h\nu = 2\pi^2 Z^2 e^4 m/h^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$. This is Balmer's formula for the hydrogen spectrum, the constant term being Rydberg's constant. It agrees very accurately.



$r = Ze^2/mv^2$

$= n^2(h^2/4\pi^2 Ze^2 m)$

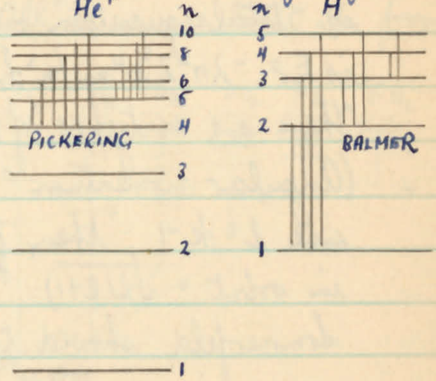
$\therefore$ Radii $\propto n^2$

8. Atomic Spectra and the Periodic Table.

The Spectrum of Ionised Helium.

Ionised helium should have similar spectrum to hydrogen, but at. no = 2 and at. wt. = 4.

$$\nu' = Z^2 R_H \left(1/n_1^2 - 1/n_2^2\right)$$



Lines almost coincide, but not quite, since the nuclea masses are different.

$$R = (2\pi^2 e^4 m / ch^3)(1/1 + m/M)$$

$$\therefore R_{He^+}/R_H = (1 + m/M_H)/(1 + m/M_{He})$$

$$= 1 + m/M_H - m/M_{He}$$

$$= 1 + m/M_H (1 - M_H/M_{He})$$

Since $M_H/M_{He} = 1/3.98$ from mass spectroscopy, $m/M_H = 1/1843$. Very good verification of Bohr theory.

Series in Line Spectra.

All spectral lines can be arranged into series, which normally overlap. Lines are not single lines but have a very narrow structure. Sommerfeld explained this using elliptical orbits.

Elliptic Orbits.

An electron has two degrees of freedom, r and θ, both of which must be quantised.

Bohr's quantisation of angular momentum is a special case of $\int p\, dq = nh$, where p = momentum, and q is position coordinate. Thus, for a Bohr orbit,

$\int_0^{2\pi r} mv.\,dx = nh = 2\pi mvr$, which is Bohr's condition.

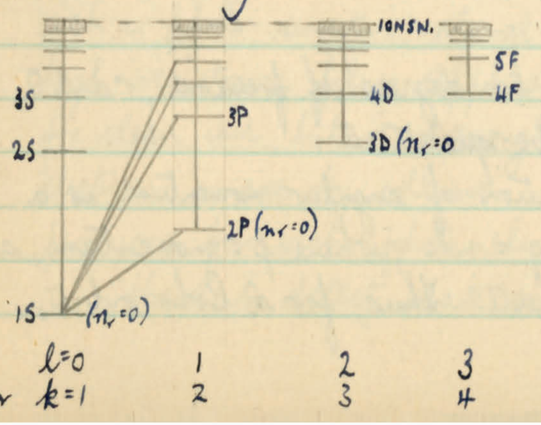
For an elliptic orbit, $\int p_\theta\, d\theta = kh$, $\int p_r\, dr = n_r h$, where p_θ, p_r are angular and radial momenta. It may be shown that $1-\varepsilon^2 = k^2/(k+n_r)^2 = b^2/a^2$. $n = k+n_r = 1, 2, 3, \ldots$ is 'total quantum number'. Total energy by Bohr's method is $E = -2\pi^2 Z^2 e^4 m / n^2 h^2 \neq f(\varepsilon)$. This is not quite true. There are n types of ellipse, for a given value of n. (Angular momentum $= kh/2\pi$ is not entirely correct. Better to use $l = k-1$; then, from wave mechanics, angular momentum in orbit $= \sqrt{l(l+1)}\cdot h/2\pi$). Simple theory shows that $E \neq f(\varepsilon)$. Sommerfeld showed that relativistic effects make the binding energy in an elliptic orbit greater than in a circular one.

One-electron Spectra.

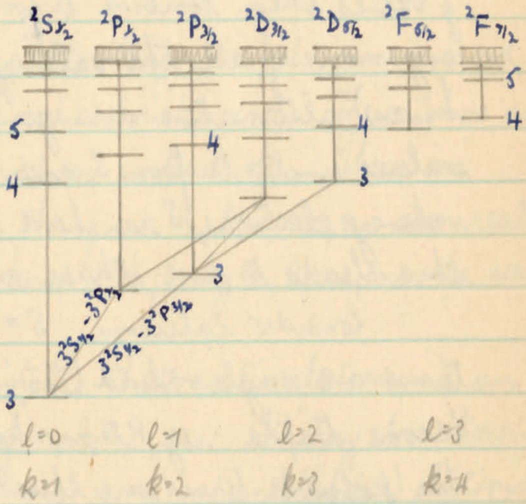
Sodium can be treated as an atom in which only 1 electron is involved in the production of the spectrum. This 'optical' electron is described by a small letter which identifies the orbit. See table:

Orbital ang. mom, l	0	1	2	3	4	5	6
Electron designation	s	p	d	f	g	h	i
Atomic state	S	P	D	F	G	H	I

When electron is in a certain orbit, atom is in a corresponding state indicated by a capital letter. The letters are only the same in one electron spectra. Orbital designations are shown: total q.n. n is placed before the letter. Transitions between specified terms can take place, the atom radiating one quantum



Sodium yellow line, was described as 1S-2P. There is a 'selection principle', which limits possible transitions to those between two terms whose l values differ by ± 1. ($\Delta l = \pm 1$). Sharp series is 2P-mS, Principal series is 1S-mP, Diffuse series is 2P-mD, Fundamental series is 3D-mF. All series are built up from terms of the form R/n_*^2, and in general, n_* is not necessarily integral. Or $R/(n-\mu)^2$, where μ is quantum defect and is almost constant for all terms in a sequence. μ increases with ellipticity, is small in f orbits.



The Spinning Electron.

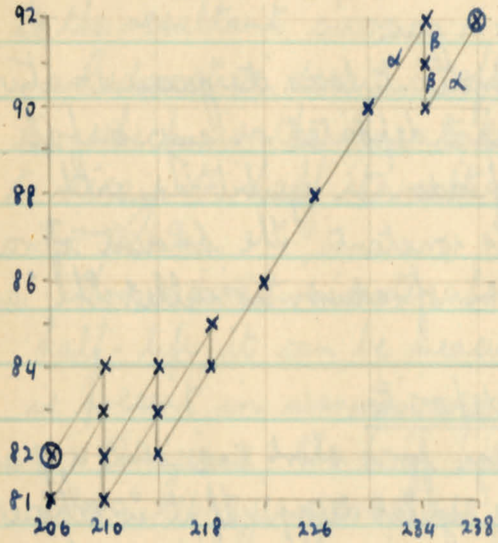
A fine structure, or 'multiplet structure,' in spectra has been known for many years.

1926 - Goudsmit and Uhlenbeck put forward theory of electron spin. Each electron has a spin $\frac{1}{2}\, h/2\pi$. Spin. ang. momentum $s\ (=\frac{1}{2})$ combines with orbit ang. momentum l to form resultant j. $j = l \pm s$. Consider Na. S terms have $l=0$, $\therefore j = \frac{1}{2}$. Term is now described as $S_{1/2}$. P terms have $l=1$ $\therefore j = \frac{1}{2}$ or $\frac{3}{2}$ and we have $P_{1/2}$ and $P_{3/2}$. Similarly for the others. Every term, except S, is double. Indicated by superscript eg $^2S_{1/2}$, $^2P_{1/2}$, $^2P_{3/2}$, etc. Sodium yellow line is 3S-3P, and is shown above. A selection principle operates, such that $\Delta j = \pm 1$ or 0. For example 3P-3D has three

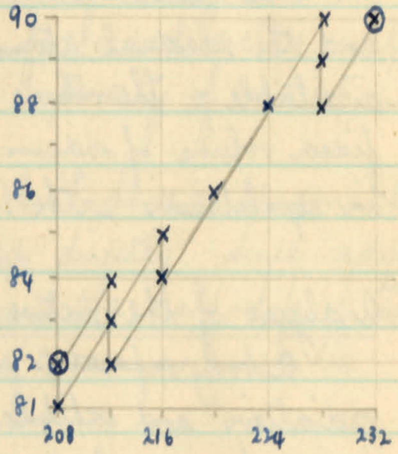
The Radioactive Series.

When all the radioactive transformations are linked up into their respective series, three main lines appear.

Uranium Series



Thorium Series



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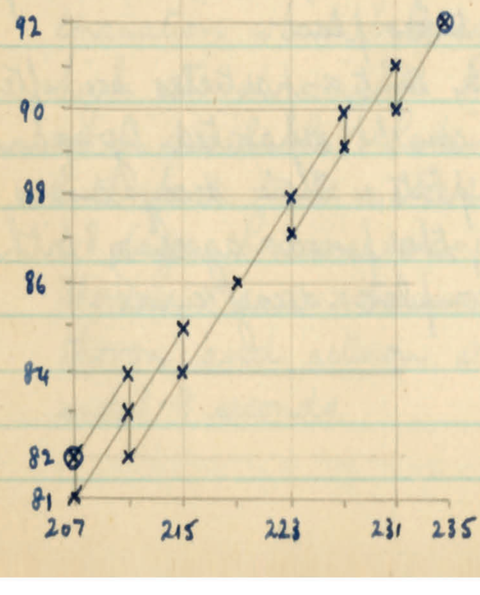
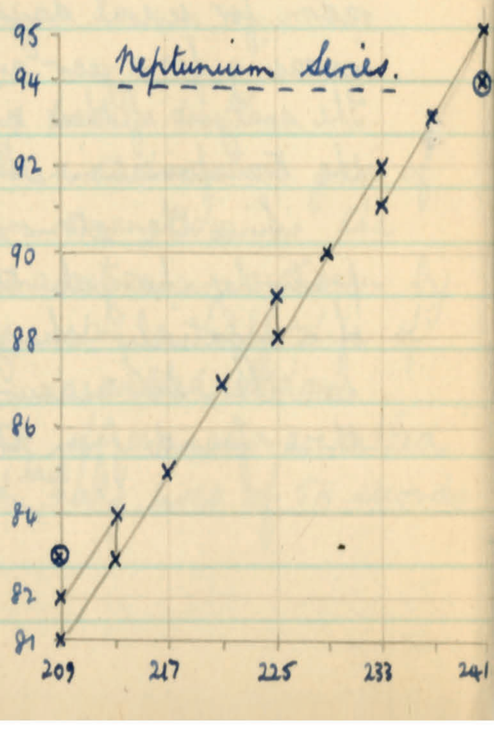
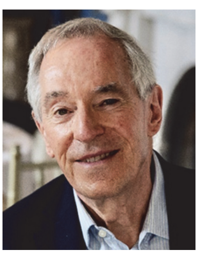


Neptunium Series.



Tina E. Kidger received a BS degree from Redditch College, Worcestershire, UK, majoring in business and education. In 1961 she was appointed Personal Assistant to Professor R. L. Goodstein, Head of Pure Mathematics, University of Leicester. Today Tina is CEO of Kidger Optics Associates. Circa 1985, she was vice president of SPIE's Exhibitor's Committee. In 1999, she established the Michael Kidger Memorial Scholarship with the assistance of SPIE and donations from Michael's many friends. She organized Michael Kidger's teaching notes and, with the help of colleagues, these were developed and published in two volumes: *Fundamental Optical Design* published by SPIE Press (2002), and *Intermediate Optical Design* published by SPIE Press (2004). Since 2004, She has held the position of European Events Consultant for Synopsys' Optical Systems Group (formerly Optical Research Associates). She is an emeritus member of the Board of Directors of the European Optical Society where she was a BOD member, c. 2002–2006. She was awarded SPIE Senior Membership in 2015 and OSA Senior Membership in 2016. In 2017, Tina assisted Professor Michael Damzen, Imperial College London (ICL) with the management of the "Optics Centenary Event" (OCE) celebrating 100 years since the founding of the Department of Technical Optics at ICL. She was OCE's opening session chair, and subsequently recorded and published "A Chronicle of the Optics Centenary Event," archived by ICL, OSA, and Harvard University. In 2019, Tina was invited by Optica (OSA) to be a member of the Adolph Lomb Medal award committee on which she served from 2019 through 2021. In January 2022, Tina was awarded the distinction of SPIE Fellow. Today Tina continues to annually award the Michael Kidger Memorial Scholarship and organize one-day optical design meetings (ODMs) in the UK and Spain, the latest being held in 2022 at University of Glasgow, UK, and February 2024 at INtech La Laguna: IACTEC, Santa Cruz de Tenerife, Spain.



Chris Dainty is Professor Emeritus at The University of Galway. He also held academic posts at The Institute of Optics, Rochester, Imperial College London, and University College London. He has co-authored 180+ peer-reviewed papers and 300+ conference papers and edited/co-authored several books. He has supervised 65 successful PhD candidates and mentored around 75 post-docs. He is the recipient of numerous awards for technical achievement, including the 1984 International Commission of Optics Prize and the 2023 Progress Medal of the Royal Photographic Society. Chris Dainty has served as President of the European Optical Society, The International Commission for Optics, and Optica. He is a member of the Royal Irish Academy.

Emery L. Moore graduated from The Pennsylvania State University with both a BSEE degree and a PhD in Physics. He also has an MSEE degree from the University of Southern California. Emery spent two years of active duty in the U.S. Navy aboard USS Forrestal (CVA-59) during which he completed a six-month tour in the Mediterranean. His professional work began as a systems engineer at North American Aviation working on inertial navigation systems for both the Minuteman Missile and then the ballistic missile submarines (SSBNs). Subsequently, Emery was employed as Advanced Technical Director at Litton Guidance and Navigation Systems Division. While at Litton, Emery led an R&D effort to develop a Nuclear Magnetic Resonance (NMR) Gyroscope under contract to the U.S.A.F. Office of Scientific Research. Subsequently, he managed Litton's effort to develop fiber optic acoustic sensors for the U.S. Navy, culminating in the award of three fiber optic acoustic sensor patents, one of which is now part of the wide aperture array aboard U.S. Navy attack submarines. Emery was President of SPIE in 1990 and now continues as a Fellow of SPIE.