D2 – THE SPARK GAP (1 MINUTES):

Attach the steel needle to the auxiliary slide carriage, in the 5000 position, using adhesive tape as illustrated, with points placed far apart.

Connect the plus to the positive and negative terminals of a 0-5,000 volt D.C. power supply, passing the cables through the cable route in the horse plate.

Locate the Spark Gap assembly as illustrated such that the needle points lie in the horse beam.

D2.1 In the absence of any illumination, increase the D.C. voltage from zero and note that a spark discharge occurs at about 1500 volts, now remove the voltage until the spark ceases.

D2.2 Select 0.5A and operate the "X-RAYS ON" button.

Note that the presence of the X-rays precipitates the spark discharge.

Switch off the lights by illuminating the Scatter Shield and note that the spark discharge ceases.

D2.3 Select 2.0A and switch on the "X-RAYS OFF" button. The discharge will only occur if the potential difference across the gap is increased.

The insulation causes variation of the air in the spark gap, the degree of which depends on the voltage across the X-rays taken electrode. It is evident, qualitatively, that X-rays cause insulating events but the technical needs to be developed for meaningful quantitative results.

D3 – THE IONISATION CHAMBER (1 HOUR):

Mount the illumination chamber, in 5S, 13 and 26 with the insulator supporting the central electrode at ES, 13 and 26 and the Carriage Are in the Primary Room.

Connect the circuit as illustrated in a D.C. Amplifier with a facility to measure current down to 10⁻¹⁰ amps., and polarise the Ionisation Chamber using a power supply with a D.C. output variable to 2000 volts.

D3.1 Ionisation at Atmosphere Pressure

Calculate the collector current I₀ for increments of polarising voltage V₀ and plot graphs A, B, C, D.

<table>
<thead>
<tr>
<th>Table A</th>
<th>Table B</th>
<th>Table C</th>
<th>Table D</th>
</tr>
</thead>
<tbody>
<tr>
<td>V₀</td>
<td>I₀</td>
<td>V₀</td>
<td>I₀</td>
</tr>
<tr>
<td>10V</td>
<td>100 mA</td>
<td>50V</td>
<td>100 mA</td>
</tr>
<tr>
<td>120V</td>
<td>150 mA</td>
<td>200V</td>
<td>150 mA</td>
</tr>
<tr>
<td>250V</td>
<td>200 mA</td>
<td>300V</td>
<td>200 mA</td>
</tr>
<tr>
<td>400V</td>
<td>250 mA</td>
<td>450V</td>
<td>250 mA</td>
</tr>
</tbody>
</table>

Notes: Do not touch the Scatter Shield during these experiments as the effect on large volumes due to electrostatic charges can distort the uniformity of the results.
Sir Lawrence Bragg presumed that the atoms of a crystal such as Sodium Chloride were arranged in a cubic and regular three-dimensional pattern. The mass of a molecule of NaCl is 58.45 kg, where \( \mathbf{N} \) is the molecular weight (58.45 x 10^2 g per mole) and \( \mathbf{N} \) is Avogadro's number (6.02 x 10^23 molecules per mole). The number of molecules per unit volume is \( \mathbf{N} \) molecules per cubic metre, where \( \mathbf{p} \) is the density (2.16 x 10^3 kg m^-3). Since NaCl is distant the number of atoms per unit volume is 2NaCl atoms per cubic metre.

The distance between adjacent atoms, \( \mathbf{d} \) in the lattice is derived from the equation

\[ \mathbf{d} = \frac{1}{2} \mathbf{NaCl} \]

and for NaCl, \( \mathbf{d} = 0.281 \) nm.

The first condition for Bragg’s equation is that the angle of incidence \( \theta \) equals the angle of reflection – this is as for optical reflection and means that any detector of the reflected rays must move through an angle \( 2\theta \), the 2:1 spectrometer relationship.

The second condition is that reflections from several layers must combine constructively:

\[ \mathbf{n} \lambda = \mathbf{d} \sin \theta = \mathbf{N} \sin \theta \]

D14.1 Mount the NaCl crystal, TLS 592.004, in the crystal holder (Part 1), para (00l) ensuring that the major face facing the West appears in the reflecting position (see Part 20.00). 1.

D14.2 Locate Primaries Beam Collector 101.001 in the Basic Fort with the low stint vial.

D14.3 Mount Sodium D Lamps (1) 562.006 at E.5 and Collector (item 1) 962.005 at E.17.

D14.4 Judder and look the SHINE plate and the Carriage are secured in position by tension from pole 1, paras. 10.00.

D14.5 Sight through the collimating slit and observe that the primary beam direction lies in the surface of the crystal.

Observe that the continuous spectra of "white" reflection exhibit peak intensities (feature 2) and intercepts on the 20 axis (feature 1) which only vary with the voltage setting of the former two.

The six steps, features 3 to 6, superimposed on the continuous spectrum do not vary in angle 20 with voltage setting, but only in amplitude.

D14.6 Calculate the residuals from the six superimposed peaks of the graph and stipulate \( \mathbf{A} \) and \( \mathbf{B} \).

<table>
<thead>
<tr>
<th>Feature</th>
<th>( \mathbf{20} )</th>
<th>( \mathbf{A} )</th>
<th>( \mathbf{B} )</th>
<th>( \mathbf{n} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>2</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>3</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>4</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>5</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>6</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
</tbody>
</table>
In the absence of micro-particles, the “resonance argument” was supported by the Larmor theory that the X-ray energy could be used as a 2-dimensional gating which would reject diffraction information by means of which the wavelength of the primary radiation could be established, but in the second version of the X-ray crystal spectrometer, this was not possible.

If, however, the wavelength of the radiation is obtained by using a non-matching crystal, as in 0-00 then a contemporary approach is to measure the position of the X-ray as per the experimental conditions.

Whereas diffuse X-ray beams are useful, the X-ray beam provides evidence that the incident radiation is both electric and magnetic, and that operation cannot be influenced by using a crystal as a diffraction gating.

The crystal clearly cannot be considered as the source of the X-ray spectrum due to photon bombardment. The continuous spectrum only begins to take shape in a measuring wavelength and cannot emerge solely by changing the X-ray tube accelerating voltage, without any variations in crystal parameters; in particular, the “resonance line” is the most intense line in X-ray absorption phenomena, but is due to the incident photon bombardment being multi-directional.

The radiation must be detected through some “inverse photoelectric effect” from the impact of the kinetic electrons on the copper target within the X-ray tube.

**D15 – X-RAY EMISSION (11/4) hours**

In selecting the copper oxide, the majority of electronic phenomena cannot be studied, and the X-ray crystal spectrometer is analyzed. With X-rays incident to the X-ray tube and general energy transfer only by changing the X-ray tube accelerating voltage, without any variations in crystal parameters; the “resonance line” is the most intense line in X-ray absorption phenomena, but is due to the incident photon bombardment being multi-directional.

The energy of electrons is the energy of X-rays, as they are accelerated through collisions with particles of energy. The energy is accelerated immeasurably, as the energy is transferred to the target particles and come in the form of electromagnetic radiation equivalent to energy in the energy. The energy is not experienced at each collision. Using these collisions usually occur of a depth and energy within the target, less magnetic, wavelengths are absorbed within the target material.

This “resonance” or “branching” is a form of continuous spectrum with a minimum wavelength for maximum energy being determined by the accelerating voltage of the tube.

\[ \lambda_{\text{min}} = \frac{1}{E} \lambda_0 \]

Where \( \lambda \) is the X-ray tube voltage selected.

**D15.1 Minimum Wavelength, Planck’s Constant**

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>( \lambda ) (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.544</td>
</tr>
<tr>
<td>70</td>
<td>0.364</td>
</tr>
<tr>
<td>50</td>
<td>0.493</td>
</tr>
<tr>
<td>30</td>
<td>0.405</td>
</tr>
</tbody>
</table>

An accurate determination of the minimum wavelength is complicated by the X-ray tube requirements that have to be regulated by a later model. The X-ray tube voltage should be set at a constant value of at least 10 second duration, the longer the time
DIL 2. Calculate the mean value for \( k \) from DIL 3 and evaluate \( \lambda \).

- \[ k \times 10^{10} \text{ coulombs}^{-1} \times 3.0 \times 10^8 \text{ m sec}^{-1} \]

Compare with the international value for \( k \) of 6.626 x 10^{-34} \text{ J sec}

The difference between the accepted standard value and the evaluated result for \( k \) is about 5%.

It is assumed that previous studies of optical spectra have established that transitions in the visible region of the electromagnetic spectrum are excited from atomic energy levels of high principal quantum number. The \( n \), \( P \), \( Q \), and \( R \) levels of the characteristic \( n \) and \( k \) lines indicate that the electron transitions at energy levels of high principal quantum number before the electron transitions in the process will cause the copper atom to ionize, and the ionized atom will result in the light being absorbed through electron transitions, each transition being accompanied by the emission of a photon of equivalent energy.

By definition, the K transition results from transitions from the \( n \) and \( K \) levels to the \( K \) level, and \( K \) from transitions from the \( K \) level to the \( L \) level. Using the line list Primary Beam Gomber, vertical, locate the doublet of the doublet K level at 6.021.4 and 6.021.9, the G.K. Table side assembly at 6.528; contact the G.K. table to a speculum for the low energy region; start the spectrometer at 0.000 and move the table upward to 0.000; the higher the counting period the greater the accuracy of the results; it is also advisable to monitor the table current and adjust as necessary to 90.0 µA.

Ensure that 1500 µA is correctly selected.

1D 4. Tabulate counts, \( T_o \), from 20° to 40° in 5° intervals.

<table>
<thead>
<tr>
<th>( \theta )</th>
<th>( T_o )</th>
<th>( T_{000} )</th>
<th>( T_{200} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°</td>
<td>( T_o )</td>
<td>( T_{000} )</td>
<td>( T_{200} )</td>
</tr>
<tr>
<td>30°</td>
<td>( T_o )</td>
<td>( T_{000} )</td>
<td>( T_{200} )</td>
</tr>
<tr>
<td>40°</td>
<td>( T_o )</td>
<td>( T_{000} )</td>
<td>( T_{200} )</td>
</tr>
</tbody>
</table>
D16.5 Locate the Copper Filter 564.004 at 5.12 and transfer counts 100.

D16.6 Calculate the ratio I_{Cu}/I_{K} and plot as a percentage Transmission against angle φ.

Transmission $\%$

<table>
<thead>
<tr>
<th>φ (°)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu f.</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Observe that the whole spectrum has been reduced in intensity but that the expected "transmission" of the Kα and Kβ lines is not evident, a very distinct discontinuity is revealed curving at a wavelength just shorter than the Kα line.

D16.7 From the graph, determine the angle 28° at which this discontinuity occurs and calculate the equivalent wavelength in accordance with the Bragg equation:

$$\lambda = 2d \sin \theta$$

The Copper Filter 564.004 at 5.12 has a finite thickness, $15.5 \times 10^{-3}$ mm, and applying the linear absorption coefficient as studied at 5.12, a 14% absorption of the radiation might be expected. This Copper does not "absorbably" absorb X-rays on characteristic emission lines Kα and Kβ in a manner compatible with the values indicated in the complete following 5.12. To ionize an atom of the Copper target in the tube, any electron from the filament must have sufficient energy to ionize an electron in the K level on which the ion level for 18 eV in emission not colorized with the compact geometry of the tube used. Thus, in hypothetical terms:

$$v_e = v_K = -10 \times 10^3 \text{ eV}$$

Following 5.12 K electron transition, a Kα photon is emitted having energy $h\nu = 1.5 \times 10^3 \text{ eV}$ (4.104 = 100 eV). This is therefore a relatively small energy difference of 100 eV.

The discontinuity occurs at a wavelength of 0.115 nm (from 5.12), which is just a few nm in wavelength than the Kα emission (about 0.14 nm from 5.12) and is evident because that a "classical photoelectric effect" was detected when some photons in the primary X-ray beam had sufficient energy to ionize the Copper atom in the foil placed at 5.12.

Furthermore, the value of the wavelength indicates that the observed plateau must be a component part of the "classical" radiation. The intensity is therefore that the Copper foil will exhibit the "absorption edge" when exposed to radiation containing energies equal to or less than the threshold of the source.

The discontinuity is thus unique to the system and is referred to as the Cu Absorption Edge.

Since the elements in the periodic table have different energy-level structures and densities, the student could use a Cu filter to find an element which will distinctly absorb Copper X-ray radiation by a systematic study using filters of different elements, but equal thicknesses.

D16.8 Remove the Copper Filter from 5.12 and replace with the Zinc Filter 565.004.

Repeat 16.5, 16.6 and 16.7.

D16.9 Remove the Zinc Filter and replace with the Nickel Filter 564.004.

Repeat 16.5, 16.6 and 16.7.

D16.10 Remove the Nickel Filter and replace with the Cobalt Filter 566.004.

Repeat 16.5, 16.6 and 16.7.

Observe that only the Cobalt Filter has absorbed or "filtered out" both the Cu emission lines but that Nickel has dramatically disturbed between the 2 and no radiation.

Clearly the absorption of X-rays is dependent not only on the thickness of the absorbing material but also on the nature of the material itself.

The linear absorption coefficient is not therefore sufficiently definitive for X-ray purposes, especially with thin foils where the effect due to the material is greater than that due to thicknesses.
D17. The equation for the Absorption Coefficient \( \mu \) is:

\[
1/\mu \text{ cm} = \log (I/I_0) = \text{absorption coefficient} \times \text{path length}.
\]

\( \mu \) is called the Mass Absorption Coefficient.

On examination of the transmission graphs drawn during the experiment, it is apparent that \( \mu \) is dependent not only on mass but also on wavelength, where an absorption edge occurs. The scales of \( \mu \), a maximum, and a minimum, are determined for the particular paper length.

The student may determine the mass and volume of the material for each absorption edge but may fit the radioactive source of the edge, accounting with the fact of thickness in the practical curve, the results will be in good agreement with the above standards.

The experiments have demonstrated that characteristic radiation is only in a few when the energy of the incident photons or electron quanta is equal to or less than the characteristic radiation edge. Conversely, if an absorption edge is observed where the beam is transmitted through which is characteristic of the absorbing material, this radiation will "broaden" indefinitely in all directions, but the maximum of the "secondary absorption" will always be slightly longer than that of the incident radiation.

D11.2. Set up for Bragg Reflections as in D11.4 to 7. Without plotting the results on paper, insert each of the 4 filters at 6.2 cm and observe the effect on output rate at features 3 and 4.

D17 - X-RAY SCATTERING (30 MINUTES)

THE X-RAY RADIATION

The Kx of the elements Zr, Cu, Co and Ni are attenuated to the tune of a mounted plastics octagonal drum and the drum located to rotate within a mounted plastics outer case which locates in the crystal post. This is the Rotary Radiator: 564.000.

The other four faces are occupied by metal elements which are sequential when classified according to their MSIC WEIGHS, as presented by the study of the Mass Absorption Coefficient in 3.6.

Zn (Zn) 65.37 Iron (Fe) 56.93
Cu (Cu) 65.36 Manganese (Mn) 56.88
Co (Co) 55.85 Chromium (Cr) 52.00
Ni (Ni) 58.71 Nickel (Ni) 54.93
Cr (Cr) 52.00

The drum is fifteen later, the angle can be used to "tune" the characteristic radiations of each element by placing the drum in turn to the window in the hood which is characterized by the radioactive source from the Copper target below the window. The source of the element in the hood is demonstrated to be shown in the second window at the front of the Rotary Radiator.

D17.4. Insert the primary collimator (Silver 962,00) into the hood at the horizontal position.

D17.5. Locate the G.M. Tube and Heater Assembly at 565.22.

Measure the intensity, \( I_0 \), for each of the elements on the Rotary Radiator:

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>MSIC</th>
<th>INTENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>65.37</td>
<td>19.8</td>
</tr>
<tr>
<td>Cu</td>
<td>65.36</td>
<td>17.5</td>
</tr>
<tr>
<td>Co</td>
<td>55.85</td>
<td>16.5</td>
</tr>
<tr>
<td>Ni</td>
<td>58.71</td>
<td>15.5</td>
</tr>
<tr>
<td>Cr</td>
<td>52.00</td>
<td>14.5</td>
</tr>
<tr>
<td>Cu</td>
<td>56.93</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Observe that the value of intensity \( I_0 \) is very considerable.

It is interesting to note that, at any "secondary" emission of X-rays from the Zn to Cu radiations, experiment 116 has demonstrated that call emission was too long or unattainable to excite the absorption edge of either Zn or Cu. If short wavelengths "limit" radiation was exciting the Zn or Cu then
The level of intensity would be very much less than that of the X-ray beam, hence to be excited by the X-ray radiation which constitutes a large proportion of the primary beam. It may be concluded therefore that some inelastic electron-experiment occurs, elastic collisions and the "scattering" out of the direction of the primary beam but without appreciable loss of energy.

0.7.6 Measure the Cs I filter at 6513 and replace with the Zn filter 36400. Measure and tabulate the intensity, I, for each element on the Rotary Radiator as in §4.5.

0.7.7 Calculate the ratio I/I_0 and plot a graph of this ratio against atomic weight

In filter

\[
\frac{I}{I_0}
\]

V, Cs, Mn, Fe, Ni, Cu, Zn

- Observe that all the points lie in a straight line with a discrepancy near the center; a rapid ascent of the experiment verifies this, in fact, it is not an experimental error.
- Observe also that although the values for I/I_0 vary for each element, when expressed as transmission there is a continuous increase in I/I_0 as the atomic weight of the "fluorescing" element increases.

As the atomic weight increases, the "fluorescence" of the element increased-thus, this gives rise to an increase in the intensity of "scattered" radiation following elastic collisions. 0.7.8 Replace the Zn filter with the Copper Filter, 36400. Tabulate the results, calculate I/I_0, and plot the transmission graph.

\[
\frac{I}{I_0}
\]

V, Cs, Mn, Fe, Ni, Cu, Zn

- Observe that the unexplained "kink" is still present, but that the straight line curve decreases at the high atomic weight end.

Evidently the radiation "fluorescence" from the Zn element is being partially absorbed by the Cu filter.

"Fluorescing" as the prime cause of this reduction can be

\[
\frac{I}{I_0}
\]

V, Cs, Mn, Fe, Ni, Cu, Zn

0.7.9 Replace the Cu Filter with the Zn filter 36400, tabulate the results, and plot the transmission graph.

Observe that an abrupt discontinuity has appeared, although a curve reman before the discontinuity is evident (for emission from the Cs radiator) and the "kink" has disappeared. It is to be expected that emission "fluorescing" from the Zn and Cu radiations will excite the element Cu, but the isolated emission seem to be partly existing clearly. Together with the absence of the "kink" the results are becoming individual to interpret, as indeed many things discovered around 1920. It would be prudent to continue the series of experiments before making further conclusions.

0.7.10 Replace the Zn filter with the Nickel Filter 36400 and tabulate and graph.

\[
\frac{I}{I_0}
\]

V, Cs, Mn, Fe, Ni, Cu, Zn

- mostly perceived that if the periodic classification of Ni and Cu were reversed, the results would exhibit a simple progression.

Distinguish the Graphs of 0.7.7, 0.7.8, 0.7.9 and 0.7.10 with the classification of Ni and Cu reversed.

\[
\frac{I}{I_0}
\]

V, Cs, Mn, Fe, Ni, Cu, Zn
absorption edge measurements for each of the eight elements used in the experiments and has been tabulated from very accurate measurements. These figures have been extracted from the International Tables.

Compare the Absorption Edge Figures given for Zn, Cu, Mo, and Sn with the results obtained in this and note the relative smoothness of the edges.

The study of scattering due to "austenite" and "ferrite" reflections provides evidence that the wavelength of the absorption edge is different and distinct for each element and that the elements are not arranged in order of decreasing wavelength.

The different dispersions of electrons in an atom depend on the population of the electrons and this in turn is associated with the nucleus. Hofstee boldly postulated that "...we have here a proof that there is in the atom a fundamental quantity which increases by regular steps as we pass from one element to the next. This quantity can only be the charge associated with the central positive nucleus."

21B - MOSELEY'S LAW (30 MINUTES)

In 1913, Sir William Henry Bragg and his son William L. Bragg made separate and systematic studies of the X-ray emission lines of the elements. They became aware that the wavelength of the emission lines of an element was associated with its atomic weight. They showed that the wavelengths were related to the atomic weights of the elements. This led to the discovery of the periodicity of the elements. This periodicity is a fundamental property of the atom and is a consequence of the electronic structure of the atom.

The following table shows the absorption and emission lines of the elements. These lines are used to determine the atomic weights of the elements.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>ATOMIC NUMBER</th>
<th>EMITTED LINE</th>
<th>ATOMIC NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>26</td>
<td>Fe Kα</td>
<td>26</td>
</tr>
<tr>
<td>Cu</td>
<td>29</td>
<td>Cu Kα</td>
<td>29</td>
</tr>
<tr>
<td>Zn</td>
<td>30</td>
<td>Zn Kα</td>
<td>30</td>
</tr>
<tr>
<td>Mo</td>
<td>42</td>
<td>Mo Kα</td>
<td>42</td>
</tr>
<tr>
<td>Sn</td>
<td>50</td>
<td>Sn Kα</td>
<td>50</td>
</tr>
</tbody>
</table>

The position of these lines reflects the periodicity of the elements. This periodicity is associated with the electronic structure of the atom and is a consequence of the electron configuration of the atom.

From the table, we can see that the wavelength of the X-ray line is related to the atomic weight of the element. This relationship is known as Molesky's Law. The law states that the wavelength of the X-ray line is inversely proportional to the square root of the atomic weight. This relationship is known as the Bragg-Brillouin Law.

The above equation can be written as

\[
\lambda = \frac{1}{\sqrt{A}}
\]

where \( \lambda \) is the wavelength of the X-ray line and \( A \) is the atomic weight of the element.

This equation can be used to determine the atomic weight of an element from its X-ray absorption or emission line. The equation can also be used to determine the wavelength of the X-ray line from the atomic weight of the element.

The above equation can be used to determine the atomic weight of an element from its X-ray absorption or emission line. The equation can also be used to determine the wavelength of the X-ray line from the atomic weight of the element.

The above equation can be used to determine the atomic weight of an element from its X-ray absorption or emission line. The equation can also be used to determine the wavelength of the X-ray line from the atomic weight of the element.
The experimental procedure is as for programme C.T.

It is perhaps a more interesting practical exercise to remove the identification from one of the 8 filters and ask the student to identify the elements by comparing at which wavelengths their absorption edges occur in relation to those of known elements.

The labels on the eight filters have been designed such that the atomic symbol can be cut away to leave only the catalogue number for identification; the numerical sequence of these numbers bears no relationship to the sequence in the Periodic Table.

Nomenclature of Moosley’s Law

No thorough investigation of absorption and scattering should be terminated without some consideration being directed to the "secondary emission emission" present when an absorption process is detected in the probability of there being some loss of energy experienced by X-ray photons when undergoing merely elastic collisions.

The accessories necessary to perform experiments D30 and D31 are not yet available.