SCHOOL OF PHYSICS
UNIVERSITI SAINS MALAYSIA

ZCT191/192 PHYSICS PRACTICAL I/II

1MP2 EXCITATION AND IONISATION POTENTIALS

Lab Manual

OBJECTIVES

1. *To determine the ionisation potential of xenon;*
2. *To determine the ionisation potential of argon; and*
3. *To show the existence of discrete energy levels in the xenon atom and determine its first excitation potential.*

THEORY

Quantisation of Energy in an Atom

In 1885, *J. J. Balmer* showed that the line spectrum of a hydrogen atom in the optical can be expressed by the series

$$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{2^2} - \frac{1}{n^2}\right), \qquad n = 3,4,5,6,\ldots \tag{1}$$

where λ is the *wavelength* of the line spectrum visible, and $R_{\mathrm{H}} = 1.097 \times 10^7\ \mathrm{m}^{-1}$ is the *Rydberg constant* for hydrogen. Although this series can predict wavelengths of the first nine spectral lines with an accuracy of 0.001, Balmer could not explain its origin theoretically.

In 1913, *Niels Bohr* came out with a theory that can explain the formula perfectly. Bohr made the following postulates:

1. An electron in an atom moves in an orbit under the influence of the *Coulombic attraction* between it and the nucleus.
4. An electron in an atom can only move in an orbit where the *angular momentum* is a multiple of $h/2\pi$, where $h = 6.626 \times 10^{-34}$ J s is the *Planck's constant*.
5. The electron orbiting the atom does not emit electromagnetic radiation despite in constant acceleration, thus the *total energy* of an atom is constant.
6. Electromagnetic radiation is emitted only when an electron with energy E_i jumps from a higher stationary state to a lower energy state E_f. The frequency f emitted can be stated as $f = (E_i - E_f)/h$.

A hydrogen atom consists of a single electron with charge $-e$ moving around a proton (nucleus) with charge $+e$, as shown in **Figure 1**.

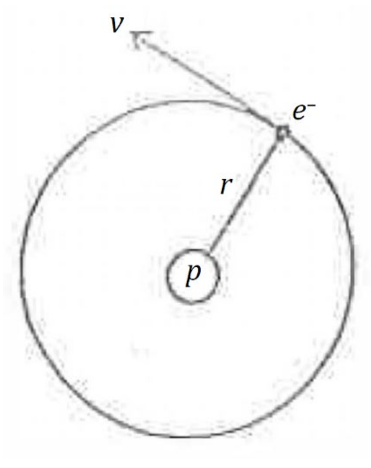

Figure 1: A model of the hydrogen atom.

According to Bohr's first postulate,

$$\frac{e^2}{4\pi\epsilon_0 r^2} = \frac{m_e v^2}{r}, \tag{2}$$

where r is the electron's *orbit radius*, v the electron's *velocity*, $e = 1.602 \times 10^{-19}$ C the *charge* of an electron, $\varepsilon_0 = 8.854 \times 10^{-12}\ \mathrm{m}^{-3}\ \mathrm{kg}^{-1}\ \mathrm{s}^4\ \mathrm{A}^2$ the *permittivity of free space*, and

$m_e = 9.109 \times 10^{-31}$ kg the *mass* of an electron. The left hand side of **Equation 2** is the *Coulomb attraction force* and the right hand side is the *centripetal force* of an electron in circular orbit.

The angular momentum (L) of an electron in orbit can be stated as $L = mvr$, and Bohr's second postulate states that,

$$mvr = \frac{nh}{2\pi}, \qquad n = 1,2,3,\ldots \tag{3}$$

From **Equations 2** and **3**, we get the radius of the orbit (r_n) and velocity of the electron (v_n) at the nth level as

$$r_n = \frac{\varepsilon_0 h^2}{\pi m e^2} n^2, \tag{4}$$

$$v_n = \frac{e^2}{2\varepsilon_0 h}\frac{1}{n}. \tag{5}$$

From **Equation 4**, the radius for the smallest orbit is $r_1 = \varepsilon_0 h^2/\pi m e^2 = 0.528$ Å, and the radii for the nth orbit can be written as

$$r_n = n^2 r_1, \tag{6}$$

thus all the orbits that can be occupied by electrons will be in the series of $r_1, 4r_1, 9r_1, 16r_1$, and etc. From Bohr's third postulate, whenever an electron occupies orbits stated in the series above, the hydrogen atom will not radiate electromagnetic radiation, and the total energy of the hydrogen atom is constant.

The *total energy* (E) of an atom can be written as $E = K + V$, where K is the *kinetic energy* and U is the *potential energy* for an electron in orbit:

$$K = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\varepsilon_0 r}, \tag{7}$$

$$U = \int_0^\infty \frac{e^2}{4\pi\varepsilon_0 r^2}dr = -\frac{e^2}{4\pi\varepsilon_0 r^2}. \tag{8}$$

Combining both, we get $E = K + V = -e^2/8\pi\varepsilon_0 r$, and writing r in terms of **Equation 4** gives

$$E_n = -\frac{me^4}{8\varepsilon_0^2 h^2}\frac{1}{n^2} = -13.6\frac{1}{n^2} \text{ eV}, \qquad n = 1,2,3,\ldots \tag{9}$$

From **Equation 9**, it is clear that the allowed energy of a hydrogen atom is *discrete*. **Figure 2** shows the energy levels for the hydrogen atom. The lowest energy level for the hydrogen atom is $E_1 = -13.6$ eV at $n = 1$. The hydrogen atom is most stable in this state, which is known as its *ground state*. If the atom absorbs enough energy, the electron can move to a higher energy level, e.g. to levels E_2, E_3, E_4, and etc. When an atom is at an energy level that is higher than the ground state $(n > 1)$, the atom is said to be in an *excited state*.

For an atom to move from state $n = 1$ to $n = 2$, the energy required is $E_2 - E_1 = -13.6(2^{-2} - 1^{-2}) = 10.21$ eV, which is illustrated in **Figure 2**. Therefore, the first excitation energy (or *excitation potential*) of hydrogen is -10.21 eV.

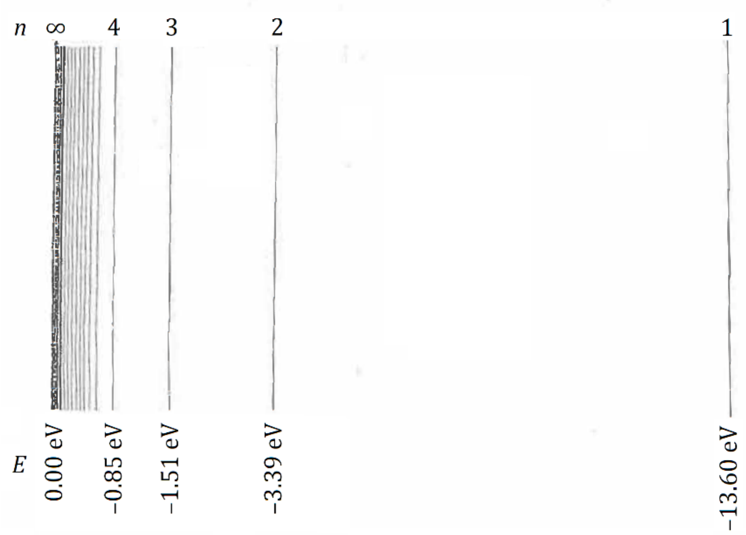

Figure 2: Discrete energy levels for the hydrogen atom.

An atom can be excited to any excitation level depending on the energy that is absorbed. If the energy absorbed reaches a critical value, the atom can be excited to $n = \infty$, so that $r_\infty = \infty$ and $E_\infty = 0$. In this condition, the electron is so far from the nucleus that it behaves effectively as a *free electron,* so the atom loses one electron and becomes a positive *ion*. In this case, *ionisation* has occurred. The free electron and the positive ion are now effectively *charge carriers*: they can take part in the *conduction* process. To ionise a hydrogen atom, the energy required is $E_\infty - E_1 = 0 - (-13.6) = 13.6$ eV. This is known as the *ionisation energy / potential* of hydrogen.

From Bohr's fourth postulate, the frequency (f) of the radiation emitted by an atom dropping from an energy level E_i to a lower level E_f is $f = (E_i - E_f)/h$, and from **Equation 9**,

$$f = -\frac{me^4}{8\varepsilon_0^2 h^3}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) = \frac{me^4}{8\varepsilon_0^2 h^3}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right). \tag{10}$$

Since $f = c/\lambda$, where c is the speed of light, we can rewrite **Equation 10** as

$$\frac{1}{\lambda} = \frac{me^4}{8\varepsilon_0^2 h^3 c}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = R_\mathrm{H}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right). \tag{11}$$

If $n_f = 2$, we obtain **Equation 1**, which is the *Balmer's series*, when the hydrogen atom is moved from states $n > 2$ to $n = 2$. With the same method, we will obtain other series, e.g. when the hydrogen atom moves from states $n > 1$ to $n = 1$, or from states $n > 3$ to $n = 3$. Predictions from Bohr's theory were verified when the other spectrum of the hydrogen series were found. The hydrogen spectrum series are listed in **Table 1**. The series can also be represented with an energy level diagram as shown in **Figure 3**.

Besides successfully explaining the hydrogen spectrum series, Bohr's theory can also be used to explain the spectrum series for hydrogen-like atoms like He^+, Li^{++} and others by substituting the Coulomb force with $Ze^2/4\pi\varepsilon_0 r^2$, where Z is the *atomic number* for that atom.

Table 1: The hydrogen spectrum series.

Series	Spectrum Formula	Wavelength Range (Å)	Discovered (Year)
Lyman	$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{1^2} - \frac{1}{n^2}\right), \quad n = 2,3,4,\ldots$	940 → 1210	1915
Balmer	$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{2^2} - \frac{1}{n^2}\right), \quad n = 3,4,5,\ldots$	3700 → 6570	1885
Paschen	$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{3^2} - \frac{1}{n^2}\right), \quad n = 4,5,6,\ldots$	8460 → 18 760	1896
Brackett	$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{4^2} - \frac{1}{n^2}\right), \quad n = 5,6,7,\ldots$	15 040 → 40 500	1922
Pfund	$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{5^2} - \frac{1}{n^2}\right), \quad n = 6,7,8,\ldots$	23 500 → 74 600	1925

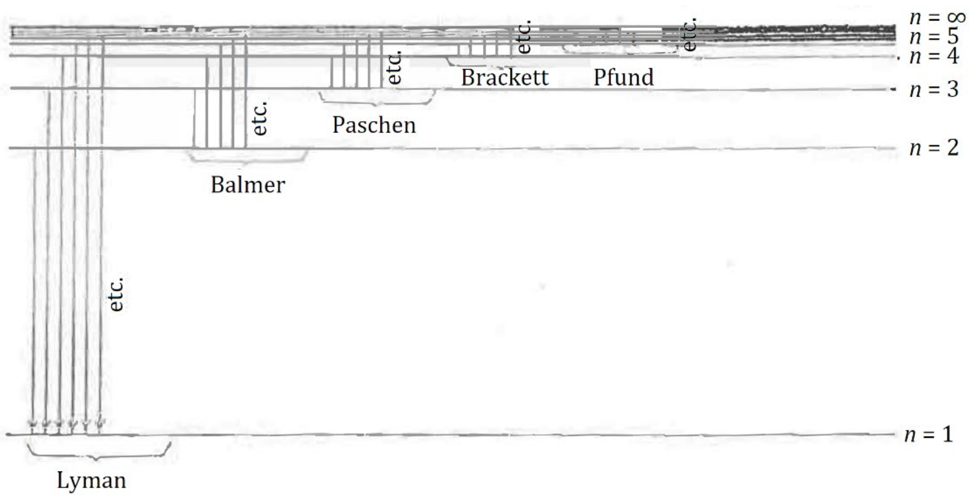

Figure 3: The energy level diagram for the hydrogen atom.

Thus, the energies of hydrogen-like atoms can be stated as

$$E_n = -Z^2 \frac{me^4}{8\varepsilon_0^2 h^2} \frac{1}{n^2}. \tag{12}$$

Although Bohr's theory successfully explained the hydrogen and hydrogen-like spectra, it has a number of flaws, as he made several ad hoc assumptions. Also, his theory is not able to explain more complex atoms, explain patterns with greater detail, or explain the brightness of the spectral lines. These problems were solved with the introduction of *quantum mechanics*.

The study of quantum mechanics was founded by Schrödinger, Heisenberg, Dirac and many others. In simplified form, a microscopic system like the electron in the hydrogen atom can be described with *Schrödinger's equation*,

$$-\frac{\hbar^2}{2m_e}\nabla^2\psi(r) + V(r)\psi(r) = E\psi(r), \tag{13}$$

where $\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial x^2 + \partial^2/\partial x^2$ is the *Laplace operator*, $V(r)$ the *potential energy* of the electron, $E(r)$ the *total energy* of the electron, and $\psi(r)$ the *wave function* of the electron. This differential equation can be solved if $V(r)$ is known, we will obtain $\psi(r)$ and hence all the information of that electron.

The solution to Schrodinger's equation will be taught later in the course *ZCT205 Quantum Mechanics*, but for the time being, we assume that

$$V(r) = -\frac{e^2}{4\pi\varepsilon_0 r}, \tag{14}$$

which is the *Coulomb potential* between an electron and a proton, which we would obtain E_n equal to **Equation 9**: the same answer as from Bohr's model. Thus, the quantisation of the energy of an atom comes naturally from quantum mechanics, which contrasts with Bohr's theory where an ad hoc assumption is required.

Until now, we have discussed only the hydrogen atom. For multi-electron atoms, one question arises: how are the electrons arranged in the atom? The answer would probably be that all electrons will occupy the lowest energy level, so that the electrons are strongly bound by the nucleus. However, due to the intrinsic *electron spin* and *Pauli's exclusion principle*, each energy level can only be occupied by a limited number of electrons.

Briefly, the number of electrons occupying each level is determined by the four quantum numbers as follows:

1. The *principal quantum number* (n), which determines the principal energy level n in Bohr's theory and can take values of $n = 1,2,3 \ldots$
2. The *orbital quantum number* (ℓ), which determines the angular momentum of the electron and can take values of $\ell = 0,1,2, \ldots, n-1$;
3. The *magnetic quantum number* (m), which determines the orbital orientation of the electron in a magnetic field and can take the values of $m = 0, \pm 1, \pm 2, \ldots, \pm \ell$;
4. The *spin quantum number* (m_s), which determines the electron spin and can take values of $m_s = \pm 1/2$.

The state of the electron in an atom can be determined if all the four quantum numbers are given. For example, the hydrogen atom at ground state and the first excited state can be stated as $(n, \ell, m, m_s) = (1,0,0, \pm 1/2)$ and $(n, \ell, m, m_s) = (2,0,0, \pm 1/2)$, respectively. Since each state can only accept one electron, not all electrons can occupy the lowest energy level in the ground state of each element. **Table A1** in the **APPENDIX** shows how the electrons are distributed at ground state for all elements up to xenon. From the table, we can see that all the lowest energy levels are occupied at ground state. If an atom absorbs enough energy, electrons at lower energy levels can be excited and jumps to higher energy levels. Therefore, the excitation and ionisation potential for hydrogen defined in **Equation 9** is also applicable for atoms with multi-electrons.

The Franck-Hertz Experiment

In 1904, *James Franck* and *Gustav Hertz* showed the existence of energy levels in an atom in their famous *Franck-Hertz experiment*. **Figure 4** shows a simplified diagram of the apparatus used by Franck and Hertz.

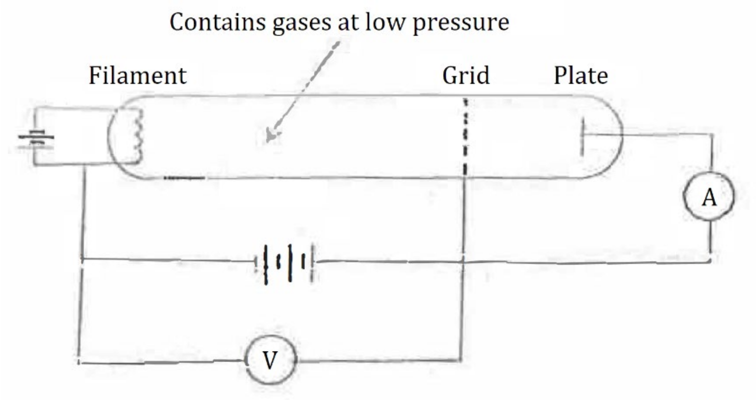

Figure 4: The schematic diagram setup for the Franck-Hertz experiment.

When there is a potential difference across the filament, electrons will be emitted as *thermion*, and they will be accelerated towards the grid. Due to the symmetry of the grid, almost all the electrons will pass through it and be collected on the plate. If the tube is empty, the plate current will increase when the grid potential increases; but if a low-temperature test gas is introduced into the tube, the electrons that are being accelerated from the grid may collide with the gas atoms in the tube. When an electron collides with an atom, the kinetic energy may be conserved (*elastic collision*), or part of the kinetic energy of the electron may be transferred to the excitation energy of the atom (*inelastic collision*). Inelastic collision can only occur if the colliding electron possesses enough kinetic energy to excite an electron in the target atom from ground energy state to a higher energy state. **Figure 5** shows the results obtained by Franck and Hertz. The first excitation energy of the gas can be determined by estimating the average separation between the minima or maxima in the graph.

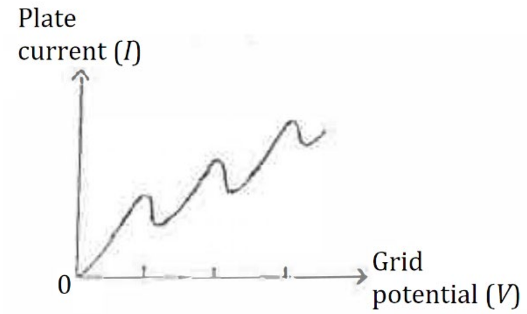

Figure 5: Typical results obtained from the Franck-Hertz experiment.

The tubes containing gases have been specially designed to show the existence of the energy levels of an atom. These tubes are expensive, and thus are not used in this experiment. As a substitution, *thyratrons* (gas-filled discharge chambers) can be used to determine the ionisation potential and to show the existence of the energy levels in atomic gases. However, not all thyratrons are suitable for this purpose depending on electrode symmetry, gas purity and gas pressure. Thyratrons containing *xenon gas* (type 2D21) and *argon gas* (type 884) can be used as the results obtained from them are close to standard values. The schematic design of a thyratron is shown in **Figure 6**.

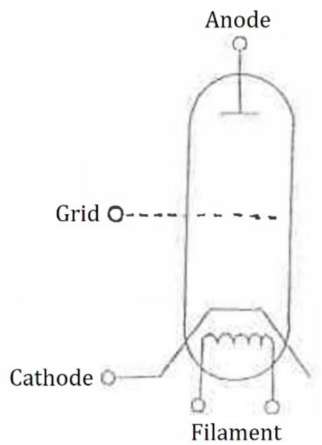

Figure 6: The design of a thyratron.

Region of Interest

One important aspect of the experiment is the determination of the *region of interest* (ROI). Usually, the required results depend on a few readings taken, thus a rough trial should be carried out at the beginning of the experiment to determine the general trend of the results obtained. From these exploratory results, the ROI can be determined, and more data in the region of interest is then collected. With this method, better results with fewer errors can be obtained without wasting time. This technique should always be used in experiments of all levels (if appropriate).

EQUIPMENT

All Experiments

1. Thyratron base
2. DC power supply (0–25 V)
3. Multi-tap AC transformer
4. Resistance box (0–100 kΩ)
5. DC voltmeter (0–30 V)
6. Connecting wires (red and black)
7. Dry cells (4 × 1.5 V) – **Part A** only
8. Thyratron 2D21 (xenon) – **Parts A** and **C** only
9. Picoammeter (Tektronix Model 6485) – **Parts A** and **C** only
10. Thyratron 884 (argon) – **Part B** only
11. DC milliammeter (0–100 mA) – **Part B** only

Picoammeter

To modify a key's properties, press the **CONFIG/LOCAL** key, and then the key (see special keys and power switch below). Note that not all keys have configurable properties.

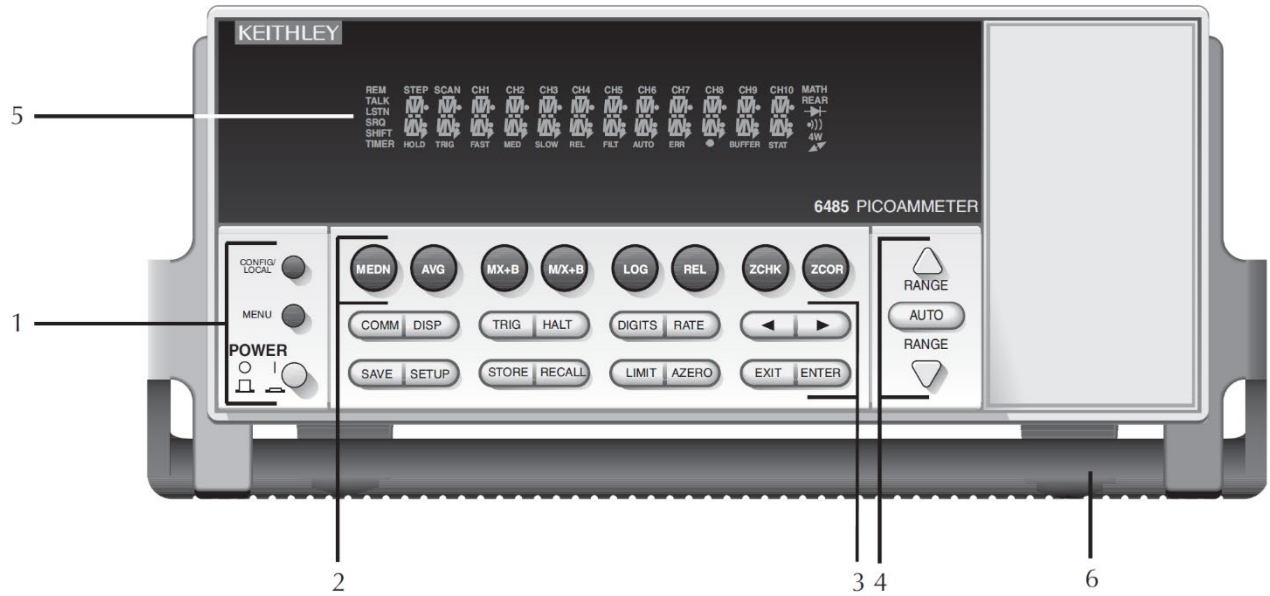

Figure 7: The front panel of the Model 6485 picoammeter.

1. **Special Keys**
   - **CONFIG/LOCAL** : when in local operation, configures properties of the next button pressed; when in remote operation (REM annunciator lit), cancels the GPIB remote mode.
   - **MENU** : accesses to menu.
   - **POWER** : on / off.

2. **Function Keys**
   - **MEDN** : median filter.
   - **AVG** : digital filter.
   - **MX+B** : $mX + b$ function.
   - **M/X+B** : $m/X + b$ function.
   - **LOG** : toggles $\log_{10}$ display.
   - **REL** : relative function.
   - **ZCHK** : zero check function.
   - **ZCOR** : zero correct function.

3. **Operation Keys**
   - **COMM** : communication (GPIB / RS-232).
   - **DISP** : display (on / off).
   - **TRIG** : triggers measurement.
   - **HALT** : stops measurement.
   - **DIGITS** : display resolution.
   - **RATE** : measurement rate.
   - **◀▶** : cursor positions.
   - **SAVE** : saves present setup.
   - **SETUP** : restores setup to GPIB / factory default / memory location.
   - **STORE** : starts buffer / modifies the number of readings to store.
   - **RECALL** : display stored readings.
   - **LIMIT** : performs limit tests.
   - **AZERO** : toggles auto zero function.
   - **EXIT** : cancels / moves back.
   - **ENTER** : accepts / moves to next.

4. **Range Keys**
   - **▲▼** : select next higher / lower measurement range.
   - **AUTO** : toggles auto range.

5. **Display Annunciators**
   - **✱** : readings stored.
   - ⤢ : additional selections.
   - **AUTO** : auto range.
   - **BUFFER** : recalling readings.
   - **ERR** : invalid calculation.
   - **FAST** : fast reading rate.
   - **FILT** : **MEDIAN/AVERAGE** enabled.
   - **LSTN** : listens over GPIB.
   - **MATH** : mX+b, m/X+b or log10 enabled.
   - **MED** : medium reading rate.
   - **REL** : relative measurement.
   - **SLOW** :slow reading rate.
   - **SRQ** : service request over **GPIB**.
   - **STAT** : buffer statistics.
   - **TALK** : talk over GPIB bus.
   - **TIMER** : timer controlled trigger.
   - **TRIG** : external trigger.

6. **Handle** (pull out and rotate to desired position)

PROCEDURE

Part A: The Ionisation Potential of Xenon

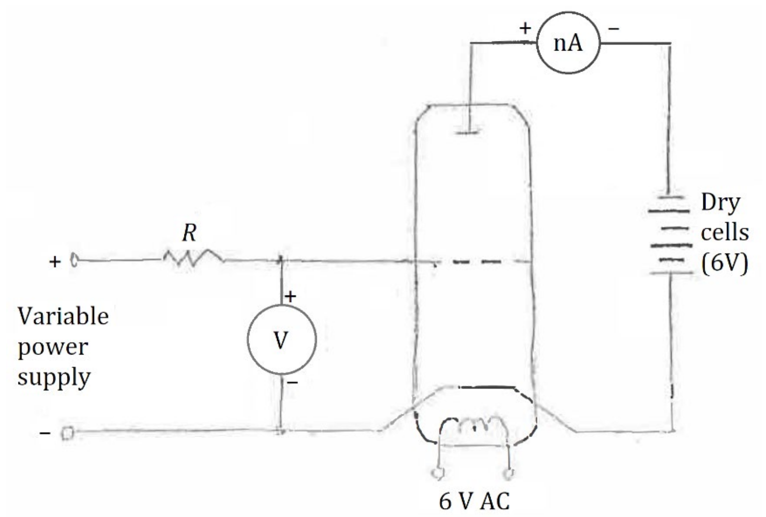

Figure 8: Circuit diagram for **Part A**.

Measurement

1. Mount the xenon thyratron on the thyratron base (the smaller one).
2. Setup the experiment circuit as shown in **Figure 1**, connecting the resistor ($R = 1\ \text{k}\Omega$), 6 V multi-tap transformer, voltmeter (0–30 V) and 6 V dry cells.
3. Connect the picoammeter via the BNC connector located at the rear. Identify and understand the function of the keys **POWER**, **ZCHK**, **ZCOR**, **DIGITS**, **RATE** and **AUTO**. For further reference, you can get a copy of the user manual from the laboratory assistant.
4. Check the connections to ensure that the polarity of the instrument terminals are correct.
5. Switch on the multi-tap transformer, and allow the thyratron to warm up for 10 minutes before beginning the experiment.
6. Switch on the picoammeter, and perform a basic zero calibration.
7. Touch the thyratron to check if it feels warm. If it is not, ensure that (a) the thyratron is seated properly, (b) the wires are tightly connected, and (c) there is input from the voltage source.
8. Increase the DC power supply voltage gradually from 0 to 14 V, then observe the readings on the voltmeter and the picoammeter. The current should increase rapidly at ~12 V, and the voltmeter reading should decrease. Re-check your circuit if this does not occur.
9. Starting from 0 V, increase the acceleration voltage (grid voltage) in steps of 1 V. Record the acceleration voltage and its corresponding current flow.

Analysis

1. Plot the anode current versus the accelerating voltage.
2. From the graph, determine the region of interest, and take additional readings in that region.
3. From the final graph, obtain the ionisation voltage of xenon.

Part B: The Ionisation Potential of Argon

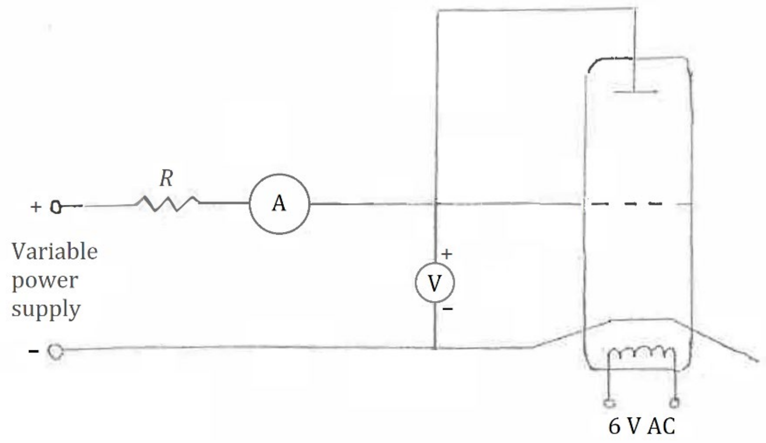

Figure 9: Circuit diagram for **Part B**.

Measurement

1. Mount the argon thyratron on the thyratron base (the bigger one).
2. Setup the experiment circuit as shown in **Figure 9**, connecting the resistor ($R = 100\ \Omega$), the 6 V multi-tap transformer, voltmeter (0–30 V), and milliammeter (0–100 mA).
3. Check the connections, especially the polarity of the instrument terminals.
4. Switch on the multi-tap transformer and allow the thyratron to warm up for 10 minutes before beginning the experiment.
5. Touch the thyratron to ensure that it is warm. If it is not, repeat the diagnostics as listed in **Step 7** of **Part A**.
6. Increase the DC power supply voltage gradually from 0 to 18 V.
7. Starting from 0 V, increase the acceleration voltage (grid voltage) in steps of 2 V. Record the acceleration voltage and its corresponding current flow.

Analysis

1. Plot the current vs. voltage.
2. From the graph, determine the region of interest, and take additional readings in that region.
3. From the final graph, obtain the ionisation voltage of argon.

Part C: The First Excitation State of Xenon

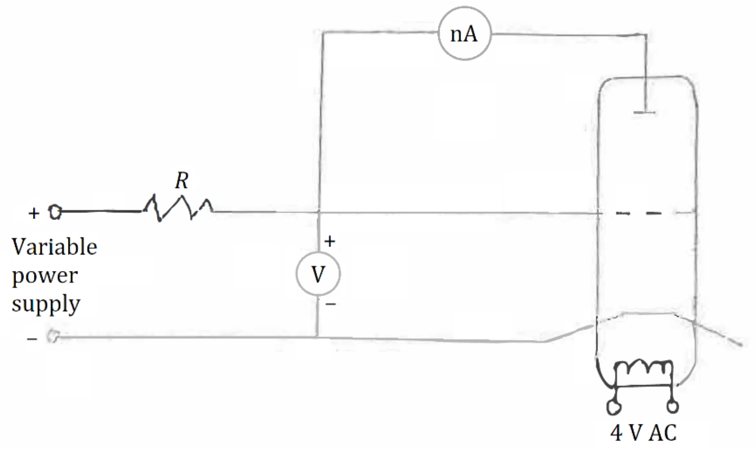

Figure 10: Circuit diagram for **Part C**.

Measurement

1. Mount the xenon thyratron on the thyratron base (the smaller base).
2. Setup the experiment circuit as shown in Figure 10, connecting the resistor ($R = 1$ kΩ), the 4 V multi-tap transformer and the voltmeter (0–30 V).
3. Check the connections, especially the polarity of the instrument terminals.
4. Switch on the multi-tap transformer and allow the thyratron to warm up for 10 minutes before beginning the experiment.
5. Switch on the picoammeter and perform basic zero calibration.
6. Touch the thyratron to ensure that it is warm. If it is not, repeat the diagnostics as listed in **Step 7** of **Part A**.
7. Increase the DC power supply voltage gradually from 0 V to 7 V, and observe the readings on the voltmeter and the picoammeter. The current should increase and then decrease with the increase in voltage. Re-check your circuit if this does not occur.
8. Starting from 0 V, increase the acceleration voltage (grid voltage) in steps of 1 V to 11 V. Record the acceleration voltage and its corresponding current flow.
9. Now increase the range of the voltmeter to 10 V and obtain additional readings from the region of interest in steps of 0.2 V. Record the results.

Analysis

1. Plot the current vs. the accelerating voltage.
2. From the graph, obtain the first excitation potential of xenon.

REFERENCES

1. Keithley Instruments (2011). *User Manual for Model 6485 Picoammeter.*

ACKNOWLEDGEMENT

This lab manual was originally created by *T. S. T.* and *L. S. H.* in 1987, edited by *Emeritus Prof. Dr. Lim Koon Ong* and *J. O.* in 1994, and translated to English by *S. K. Fong* and *F. S. K.* in 2008. This manual was revised and standardised by *Dr. John Soo Yue Han* in 2021.

APPENDIX

Table A1: A list of elements with their respective electron configuration.

	K	***L***		***M***			***N***			***O***	
	1*s*	**2*s***	**2*p***	**3*s***	**3*p***	**3*d***	**4*s***	**4*p***	**4*d***	**5*s***	**5*p***
^{1}H	1										
^{2}He	2										
^{3}Li	2	1									
^{4}Be	2	2									
^{5}B	2	2	1								
^{6}C	2	2	2								
^{7}N	2	2	3								
^{8}O	2	2	4								
^{9}F	2	2	5								
^{10}Ne	2	2	6								
^{11}Na	2	2	6	1							
^{12}Mg	2	2	6	2							
^{13}Al	2	2	6	2	1						
^{14}Si	2	2	6	2	2						
^{15}P	2	2	6	2	3						
^{16}S	2	2	6	2	4						
^{17}Cl	2	2	6	2	5						
^{18}Ar	**2**	**2**	**6**	**2**	**6**						
^{19}K	2	2	6	2	6		1				
^{20}Ca	2	2	6	2	6		2				
^{21}Sc	2	2	6	2	6	1	2				
^{22}Ti	2	2	6	2	6	2	2				
^{23}V	2	2	6	2	6	3	2				
^{24}Cr	2	2	6	2	6	5	1				
^{25}Mn	2	2	6	2	6	5	2				
^{26}Fe	2	2	6	2	6	6	2				
^{27}Co	2	2	6	2	6	7	2				
^{28}Ni	2	2	6	2	6	8	2				
^{29}Cu	2	2	6	2	6	10	1				
^{30}Zn	2	2	6	2	6	10	2				
^{31}Ga	2	2	6	2	6	10	2	1			
^{32}Ge	2	2	6	2	6	10	2	2			
^{33}As	2	2	6	2	6	10	2	3			
^{34}Se	2	2	6	2	6	10	2	4			
^{35}Br	2	2	6	2	6	10	2	5			
^{36}Kr	2	2	6	2	6	10	2	6			
^{37}Rb	2	2	6	2	6	10	2	6		1	
^{38}Sr	2	2	6	2	6	10	2	6		2	

	K	***L***		***M***			***N***			***O***	
	1*s*	**2*s***	**2*p***	**3*s***	**3*p***	**3*d***	**4*s***	**4*p***	**4*d***	**5*s***	**5*p***
^{39}Y	2	2	6	2	6	10	2	6	1	2	
^{40}Zr	2	2	6	2	6	10	2	6	2	2	
^{41}Nb	2	2	6	2	6	10	2	6	4	1	
^{42}Mo	2	2	6	2	6	10	2	6	5	1	
^{43}Tc	2	2	6	2	6	10	2	6	5	2	
^{44}Ru	2	2	6	2	6	10	2	6	7	1	
^{45}Rh	2	2	6	2	6	10	2	6	8	1	
^{46}Pd	2	2	6	2	6	10	2	6	10		
^{47}Ag	2	2	6	2	6	10	2	6	10	1	
^{48}Cd	2	2	6	2	6	10	2	6	10	2	
^{49}In	2	2	6	2	6	10	2	6	10	2	1
^{50}Sn	2	2	6	2	6	10	2	6	10	2	2
^{51}Sb	2	2	6	2	6	10	2	6	10	2	3
^{52}Te	2	2	6	2	6	10	2	6	10	2	4
^{53}I	2	2	6	2	6	10	2	6	10	2	5
^{54}Xe	**2**	**2**	**6**	**2**	**6**	**10**	**2**	**6**	**10**	**2**	**6**

Last Updated: 13 September 2021 (JSYH)