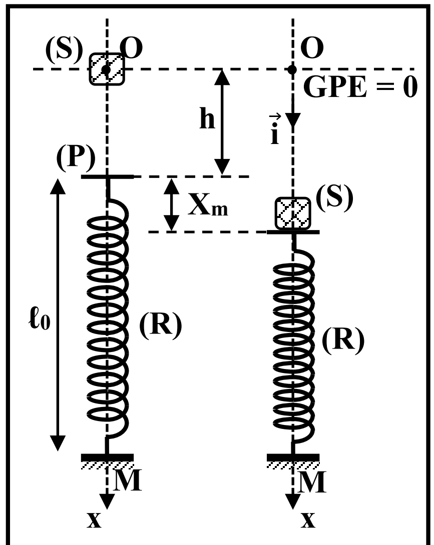
مسابقة في مادة الفيزياء	الاسم:
المدة: ساعة ونصف	الرقم:

يتكوّن هذا الامتحان من خمسة تمارين، موزعة على أربع صفحات. يجب اختيار **ثلاثة تمارين فقط**.
إقرأ الأسئلة كلّها بشكل عام وشامل، ومن ثمّ حدّد اختياراتك.
ملاحظة: في حال الإجابة عن أكثر من ثلاثة تمارين، عليك شطب الإجابات المتعلقة بالتمارين التي لم تعد من ضمن اختيارك، لأن التصحيح يقتصر على إجابات التمارين الثلاث الأولى غير المشطوبة، بحسب ترتيبها على ورقة الإجابة. يمكن الاستعانة بالآلة الحاسبة غير القابلة للبرمجة.
تعطى نصف علامة على وضوح الخط والترتيب.

Exercise 1 (6.5 pts) Mechanical energy

A massless spring (R), of natural length ℓ_0 and of stiffness (spring constant) k, is placed vertically. The lower extremity of (R) is fixed to a support at point M and the upper extremity is welded to a massless plate (P).
An object (S), considered as a particle of mass m = 200 g, is launched, at $t_0 = 0$, vertically downward with a velocity $\vec{V_0} = V_0\,\vec{i}$ from point O situated at a height h = 100 cm above (P). Point O is the origin of the x-axis of unit vector $\vec{i}$, directed vertically downward.
At $t = t_1$, (S) collides with (P) and sticks to it; thus forming a single body [(P), (S)] considered as a particle (Doc. 1).
The aim of this exercise is to determine the spring constant k.



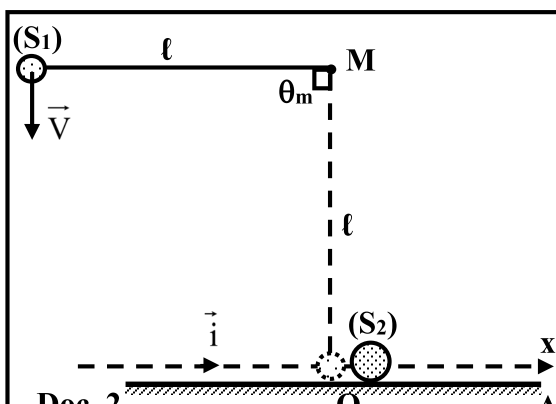
Doc. 1

Take:
- the horizontal plane passing through O as a reference level for gravitational potential energy;
- $g = 10\ m/s^2$.

1) E_1 and E_2 are the expressions, as functions of time, of the kinetic energy KE of (S) and the gravitational potential energy GPE of the system [(S) - Earth] between $t_0 = 0$ and $t = t_1$.
$E_1 = -10\,t^2 - 24\,t$ (SI) ; $E_2 = 10\,t^2 + 24\,t + 14.4$ (SI).
Match each of E_1 and E_2 with the appropriate form of energy.
Justify your answer for each energy.
2) Determine V_0.
3) Calculate between t_0 and t_1, the mechanical energy of the system [(S) - Earth].
4) Deduce that friction is neglected between t_0 and t_1.
5) Show that the gravitational potential energy of the system [(S) - Earth] at t_1 is $GPE_1 = -2$ J.
6) Deduce the kinetic energy of (S) at t_1.
7) After t_1, the forces of friction are still negligible. The mechanical energy of the system [(S), (P), (R), Earth] is ME = 14.4 J. At $t = t_2$, the spring (R) attains its maximum compression $X_m = 10$ cm and remains vertical along the x-axis.
7.1) Show that the elastic potential energy $PE_{elastic}$ of the system [(S), (P), (R), Earth] at $t = t_2$ is $PE_{elastic} = 16.6$ J.
7.2) Deduce the value of k.

Exercise 2 (6.5 pts) Energy and collision

Consider a simple pendulum formed of a sphere (S_1), taken as a particle, of mass $m_1 = 0.1$ kg, suspended from the lower extremity of a light inextensible string of length $\ell = 40$ cm.
The upper extremity of the string is fixed, at M, to a support.
The pendulum is shifted in the vertical plane by an angle $\theta_m = 90°$. The string remains taut, (S_1) is launched, at $t_0 = 0$, with a velocity $\vec{V}$, of magnitude V directed vertically downward.



Doc. 2

When the pendulum reaches the equilibrium position, at O, (S_1) enters a head-on elastic collision with a sphere (S_2), taken as a particle, of mass $m_2 = 0.3$ kg, initially at rest at O on a horizontal surface.

O is the origin of the horizontal x-axis of unit vector $\vec{i}$.

After collision (S_2) moves along the x-axis and stops at point A (Doc. 2).

Between O and A, (S_2) is subjected to a force of friction $\vec{f}$, supposed constant, and parallel to the displacement.

The aim of this exercise is to determine the magnitude f of the force of friction $\vec{f}$.

Neglect air resistance and the friction around M.

Take:

- the horizontal plane containing (OA) as a reference level for gravitational potential energy;
- $g = 10\ m/s^2$.

1) Determine, at $t_0 = 0$, the expression of the mechanical energy of the system (Pendulum, Earth) in terms of V.

2) Calculate V, knowing that (S_1) reaches the equilibrium position at O with a speed $V_1 = 6$ m/s.

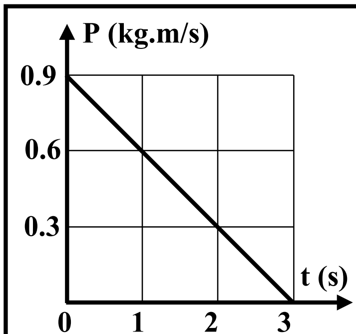
3) When (S_1) passes through the equilibrium position, at O, (S_1) enters a head-on elastic collision with (S_2). $\vec{v'_1}$ and $\vec{v'_2}$ are the velocities of (S_1) and (S_2) respectively just after this collision. $\vec{v'_1}$ and $\vec{v'_2}$ are collinear along the x-axis.

3.1) Show that the relations between the algebraic values of the velocities $\vec{v'_1}$ and $\vec{v'_2}$ are given by: $v'_1 + 3\,v'_2 = 6$ and $v'_2 - v'_1 = 6$ (SI)

3.2) Using the result of part 3.1, calculate v'_1 and v'_2.

4) Just after the collision, (S_2) leaves point O with the velocity $\vec{v'_2}$, at an instant $t_0 = 0$ s taken as a new initial time, and moves along the x-axis.

The curve of document 3 represents the value of the linear momentum P of (S_2) as a function of time, during its motion between O and A.



Doc. 3

4.1) Referring to document 3, determine the expression of P as a function of time.

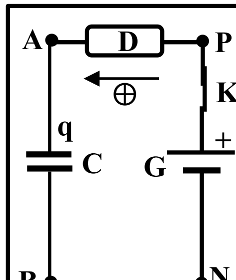
4.2) By applying Newton's second law $\Sigma \vec{F}_{ext} = \frac{d\vec{P}}{dt}$ on (S_2), deduce f.

Exercise 3 (6.5 pts) — Dielectric of a capacitor

A capacitor is formed of two conducting plates separated by an insulator of thickness « e » called dielectric.

The aim of this exercise is to study the influence of the thickness « e » of the dielectric of a capacitor on the value of its capacitance.

For this purpose, we set up the series circuit of document 4 that includes:



Doc. 4

- an ideal battery (G) of electromotive force E = 24 V;
- a resistor (D) of resistance R = 100 kΩ;
- a capacitor, initially uncharged, of capacitance C;
- a switch K.

1) Capacitance of the capacitor

At the instant $t_0 = 0$, K is closed and the charging process of the capacitor starts.

At an instant t, plate A of the capacitor carries a charge q, and the circuit carries a current i.

1.1) Determine the relation among i, C and the voltage $u_{AB} = u_C$ across the capacitor.

1.2) Show that the differential equation that describes the variation of $u_{AB} = u_C$ is: $E = RC\frac{du_C}{dt} + u_C$.

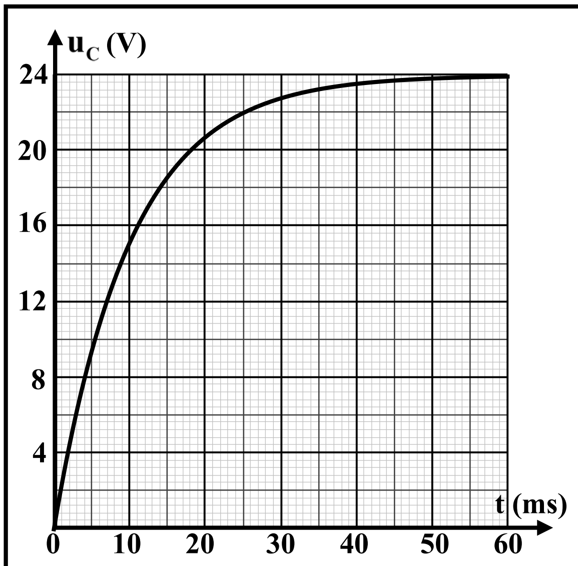
1.3) The solution of the obtained differential equation has the form: $u_C = E\left(1 - e^{\frac{-t}{\tau}}\right)$ where τ is a constant.

Determine the expression of τ in terms of R and C.

1.4) Show that $t = \tau \ln 2$, when $u_C = \frac{E}{2}$.

1.5) The graph of document 5 shows u_C as a function of time. Using the result of part (1.4) and by referring to document 5, determine the value of τ.

1.6) Deduce the value of C.



Doc. 5

2) Thickness of the dielectric

The graph of document 6 shows C versus $\frac{1}{e}$.

2.1) Choose with justification, the correct expression:

Expression 1: The capacitance of the capacitor is proportional to the thickness of the dielectric.

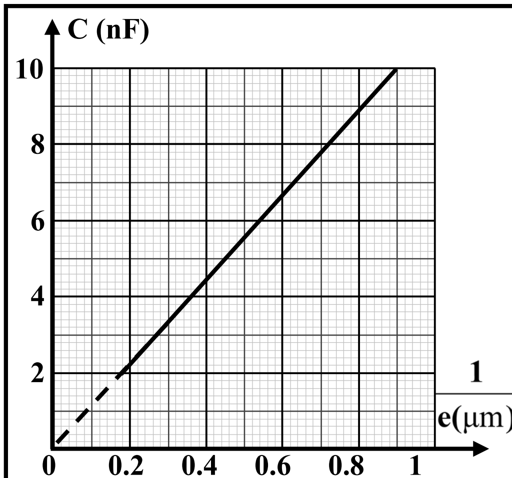
Expression 2: The capacitance of the capacitor is inversely proportional to the thickness of the dielectric.

Expression 3: The capacitance of the capacitor is proportional to the square of the thickness of the dielectric.

2.2) Referring to the curve of document 6, show that:

$C = 11.1 \times \frac{1}{e}$ (C in nF and e in µm).

2.3) Deduce the value of the thickness « e » of the dielectric of the capacitor in part 1.



Doc. 6

Exercise 4 (6.5 pts) **Photoelectric effect**

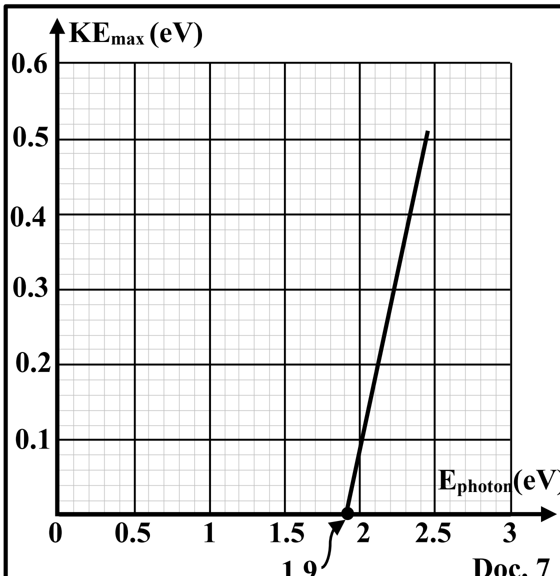
The phenomenon of photoelectric effect can be observed when a cesium plate is illuminated by a source of monochromatic light beam of adjustable frequency.

A device is used to measure the maximum kinetic energy « KE_{max} » of an emitted electron, corresponding to the energy of the incident photon « E_{photon} » of a beam which illuminates the cesium plate whose extraction energy (work function) is « W_0 ».

The graph of document 7 shows « KE_{max} » as a function of « E_{photon} ».

Given:

- Speed of light in vacuum $c = 3\times10^{8}$ m/s;
- Planck's constant $h = 6.6\times10^{-34}$ J.s;
- Elementary charge $e = 1.6\times10^{-19}$ C;
- 1 eV = 1.6×10^{-19} J.



Doc. 7

1) Define « photoelectric effect ».

2) Copy and complete, using document 7, the table below with the convenient expression:

- **Expression 1**: electrons are ejected from the surface of cesium with non-zero kinetic energy;
- **Expression 2**: electrons are not ejected from the surface of cesium;
- **Expression 3**: electrons are extracted from the surface of cesium with zero kinetic energy.

$E_{photon} < 1.9$ eV	$E_{photon} = 1.9$ eV	$E_{photon} > 1.9$ eV

3) Indicate then the value of W_0 of cesium.

4) The cesium plate is illuminated by a source of light of wavelength λ in vacuum. The maximum kinetic energy of the emitted electrons is $KE_{max} = 0.16$ eV.

4.1) Determine the value of λ.

4.2) The power of the beam received by the plate of cesium is P = 4.5 W.
Calculate the number N of the photons received by the plate in one second.

4.3) The emitted electrons from the plate of cesium form a current I = 0.1 A.
Determine, in one second, the number n of the effective photons.

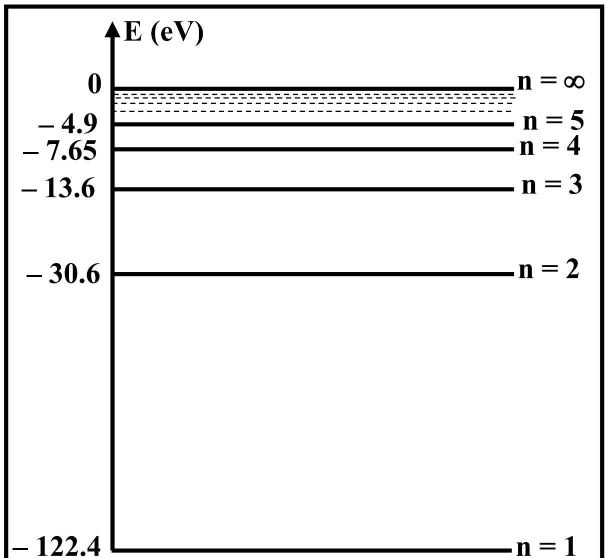
4.4) Deduce the quantum efficiency $r = \frac{n}{N}$ of the plate.

Exercise 5 (6.5 pts) Lithium atom

The energies of the various levels of a doubly-ionized Li^{2+} atom are given by the relation:

$E_n = -\frac{122.4}{n^2}$, where n is a non-zero positive whole number and E_n is in eV.

Document 8 shows a simplified diagram of the energy levels of Li^{2+}ion.



Doc. 8

Given:

Planck's constant $h = 6.62\times10^{-34}$ J.s;

1 eV = 1.6×10^{-19} J;

Speed of light in vacuum: $c = 3\times10^{8}$ m/s.

Visible spectrum in vacuum: $0.400\ \mu m \leq \lambda \leq 0.750\ \mu m$.

1) Using document 8, show that the energy of Li^{2+} ion is quantized.

2) The lithium ion Li^{2+}undergoes a transition from an energy level E_n to the ground level E_1, it emits a photon of wavelength λ.

2.1) Show that: $\lambda = \frac{0.01014}{1-\frac{1}{n^2}}$, λ in μm and n > 1.

2.2) Calculate, in μm, the maximum wavelength λ_{max} and the minimum wavelength λ_{min} emitted during the de-excitation of lithium ion Li^{2+} to the ground state.

3) The lithium ion Li^{2+} is in the second excited state. The de-excitation of the lithium ion can occur through three different transitions.

3.1) Indicate these three transitions.

3.2) Calculate the wavelengths corresponding to these transitions.

3.3) Specify the domain (visible, infrared, or ultraviolet), of the radiation corresponding to each transition.

مسابقة في مادة الفيزياء
أسس التصحيح - إنكليزي

Exercise 1 (6.5pts)	Mechanical energy	
Part	**Answer**	**Mark**
1	E_1 represents gravitational potential energy. Since at t = 0: E_1 = 0 and at t = 0: (S) is at O (reference level of GPE) which means that GPE = 0. E_2 represents kinetic energy. Since at t = 0: E_2 = 14.4 J , at t = 0, it is given that (S) is launched with a velocity so KE $\neq 0$.	**0.25** **0.25** **0.25** **0.25**
2	At t = 0 : KE = 14.4 J , but KE = $\frac{1}{2}\text{m } V_0^2$ So: $14.4 = \frac{1}{2} \times 0.2 \times V_0^2$ therefore V_0 = 12 m/s	**1**
3	ME = KE + GPE , ME = $-10\,t^2 - 24\,t + 10\,t^2 + 24\,t + 14.4 = 14.4$ J	**0.5**
4	Since ME is conserved then force of friction is neglected	**0.5**
5	At t_1: GPE = – m g h = – 0.2×10×1 = – 2 J	**0.5**
6	ME = KE + GPE , so KE = ME – GPE , this implies: KE = 14.4 + 2 = 16.4 J	**0.75**
7 — **7.1**	At t = t_2: ME = KE + GPE + $PE_{elastic}$, So $PE_{elastic}$ = ME – KE – GPE , thus $PE_{elastic}$ = 14.4 – 0 – (– 0.2×10×1.1) = 16.6 J	**1.25**
7 — **7.2**	$PE_{elastic} = \frac{1}{2}kX_m^2$, So $16.6 = \frac{1}{2}k(0.1)^2$ this implies k = 3320 N/m	**1**

Exercise 2 (6.5pts)	Energy and collision	
Part	**Answer**	**Mark**
1	ME = KE + GPE , so $ME_0 = \frac{1}{2} m_1 V^2 + m\,g\,\ell = \frac{1}{2} \times 0.1 \times V^2 + 0.1 \times 10 \times 0.4$. This implies: $ME_0 = 0.05\,V^2 + 0.4$.	**1**
2	$ME_O = ME_0$, so $\frac{1}{2} m_1 V_1^2 + 0 = 0.05\,V^2 + 0.4$, This implies: $\frac{1}{2} \times 0.1 \times 36 = 0.05\,V^2 + 0.4$, thus V = 5.29 m/s	**1**
3.1	**Conservation of linear momentum** $\vec{P}_{before} = \vec{P}_{after} \Rightarrow m_1\,\vec{V}_1 = m_1\,\vec{v}'_1 + m_2\,\vec{v}'_2$, by taking the algebraic values: $0.1 V_1 = 0.1\,v'_1 + 0.3\,v'_2$, this implies: $V_1 - v'_1 = 3\,v'_2$ …. eq. (1) **Conservation of kinetic energy** $KE_{before} = KE_{after} \Rightarrow \frac{1}{2} m_1\,V_1^2 = \frac{1}{2} m_1\,v'^2_1 + \frac{1}{2}\,m_2\,v'^2_2$, so: $0.1 \times V_1^2 = 0.1\,v'^2_1 + 0.3 \times v'^2_2$, this implies: $V_1^2 - v'^2_1 = 3\,v'^2_2$ … eq. (2) $\frac{eq.(2)}{eq.(1)}$: $V_1 + v'_1 = v'_2$. This implies: $v'_2 - v'_1 = 6$. Eq. (1) : $V_1 - v'_1 = 3\,v'_2$. This implies $v'_1 + 3\,v'_2 = 6$	**1.5**
3.2	$v'_1 + 3\,v'_2 = 6$ and $v'_2 - v'_1 = 6$. If we add the 2 equations, we get: $4\,v'_2 = 12$, thus $v'_2 = 3$ m/s. Substitute in any equation, we get: $v'_1 = -3$ m/s	**0.5** **0.5**
4.1	P = at + b At t = 0: P = 0.9, so b = 0.9 At t = 3: P = 0, so 0 = 3 a + 0.9 , this implies a = – 0.3 , So: P = – 0.3 t + 0.9 (SI)	**1**
4.2	By applying Newton's second law on (S_2): $\Sigma \overrightarrow{F_{ext}} = \frac{d\vec{P}}{dt}$ then $m\vec{g} + \vec{N} + \vec{f} = \frac{d\vec{P}}{dt}$ But $m\vec{g} + \vec{N} = \vec{0}$ horizontal motion $-0.3\,\vec{i} = -f\,\vec{i}$ then **f = 0.3 N**	**1**

Exercise 3 (6.5 pts)	Dielectric of a capacitor	
Part	**Answer**	**Mark**
1.1	$i = \frac{dq}{dt}$, but $q = C\,u_C$, so $\frac{dq}{dt} = C\frac{du_C}{dt}$ this implies that : $i = C\frac{du_C}{dt}$	**0.5**
1.2	$u_{PN} = u_{PA} + u_{AB} + u_{BN}$ $E = u_C + R.\,i$ this implies that: $E = u_C + RC\frac{du_C}{dt}$	**0.5**
1.3	$u_C = E\left(1 - e^{\frac{-t}{\tau}}\right) = E - E\,e^{\frac{-t}{\tau}}$ So: $\frac{du_C}{dt} = \frac{E}{\tau}e^{\frac{-t}{\tau}}$ Substitute in the differential equation: $RC\frac{du_C}{dt} + u_C = E$; so $RC\frac{E}{\tau}e^{\frac{-t}{\tau}} + E - E\,e^{\frac{-t}{\tau}} = E$ $E\,e^{\frac{-t}{\tau}}\left(\frac{RC}{\tau} - 1\right) = 0$; But $E\,e^{\frac{-t}{\tau}} \neq 0$; This implies: $\frac{RC}{\tau} - 1 = 0$; thus: $\tau = R\,C$	**1**
1.4	$u_C = \frac{E}{2}$; so, $E\left(1 - e^{\frac{-t}{\tau}}\right) = \frac{E}{2}$ this implies: $1 - e^{\frac{-t}{\tau}} = \frac{1}{2}$; so, $e^{\frac{-t}{\tau}} = \frac{1}{2}$ ℓn both sides: $\frac{-t}{\tau} = -\,\ell n(2)$, We get: $t = \tau\,\ell n(2)$	**1**
1.5	Graphically: $u_C = \frac{E}{2} = 12$ V; at t = 7 ms. But $t = \tau\,\ell n(2)$; so, $7 = \tau\,\ell n(2)$; This implies: $\tau = 10$ ms	**1**
1.6	$\tau = R\,C$; So, 0.01= 100 000 C ; Thus $C = 10^{-7}$ F = 100 nF	**0.5**
2.1	**Expression 2:** The capacitance of a capacitor is inversely proportional to the thickness of the dielectric. **Justification**: Since the shape of the curve is a straight line whose extension passes through the origin, its equation is of the form: : $C = \text{slope} \times \frac{1}{e}$ then C and e are inversely proportional	**1**
2.2	The shape of the curve is a straight line whose extension passes through the origin, its equation is of the form: : $C = \text{slope} \times \frac{1}{e}$; Graphically: slope $= \frac{10 - 2.2}{0.9 - 0.2} = 11.1$ nF.µm **<u>Or</u>** for C = 10 nF ; $\frac{1}{e} = 0.9$ Then slope = 11.1 nF×µm = cst Therefore $C = 11.1 \times \frac{1}{e}$	**0.5**
2.3	For C = 100 nF we obtain $e = \frac{11.1}{100} = 0.11$ µm	**0.5**

<table>
<tr><th colspan="3">Exercise 4 (6.5 points) photoelectric effect</th></tr>
<tr><th>Part</th><th>Answer</th><th>Mark</th></tr>
<tr><td>1</td><td>Photoelectric effect is the phenomenon of the emission of electrons from the surface of a pure metal when illuminated by convenient radiation (electromagnetic radiation)</td><td>0.5</td></tr>
<tr><td>2</td><td>

$E_{photon} < 1.9$ eV	$E_{photon} = 1.9$ eV	$E_{photon} > 1.9$ eV
Expression 2: electron are not ejected from the surface of the cesium.	**Expression 3:** electrons are extracted from the surface of the cesium with zero kinetic energy	**Expression 1:** electrons are ejected from the surface of cesium with non - zero kinetic energy

</td><td>0.5
0.5
0.5</td></tr>
<tr><td>3</td><td>$W_0 = 1.9$ eV</td><td>0.5</td></tr>
<tr><td>4.1</td><td>According to Einstein's relation: $E_{photon} = W_0 + KE_{max}$

$\frac{hc}{\lambda} = W_0 + KE_{max}$ So $\frac{hc}{\lambda} = (1.9 + 0.16)\times1.6\times10^{-19}$,

Then $\lambda = \frac{6.6\times10^{-34}\times3\times10^{8}}{(1.9+0.16)\times1.6\times10^{-19}}$, this implies: $\lambda \cong 600\times10^{-9}$ m = 600 nm</td><td>1</td></tr>
<tr><td>4.2</td><td>$P = \frac{N\times E_{photon}}{\Delta t}$, so $N = \frac{P\times\Delta t}{E_{photon}}$,

But $E_{photon} = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{600\times10^{-9}} = 3.3\times10^{-19}$ J,

This implies: $N = \frac{4.5\times1}{3.3\times10^{-19}} \cong 1.36\times10^{19}$ photons</td><td>1</td></tr>
<tr><td>4.3</td><td>$I = \frac{q}{\Delta t}$ and $q = n\,e$, then $I = \frac{n\times e}{\Delta t}$,

So $0.1 = \frac{n\times1.6\times10^{-19}}{1}$, this implies; $n = 6.25\times10^{17}$ electrons

The number of effective photons = the number of emitted electrons = 6.25×10^{17}</td><td>1
0.5</td></tr>
<tr><td>4.4</td><td>$r = \frac{n}{N} = \frac{6.25\times10^{17}}{1.36\times10^{19}} = 0.0459 = 4.59$ %</td><td>0.5</td></tr>
</table>

Exercise 5 (6.5 pts)	Lithium atom	
Part	**Answer**	**Mark**
1	We have only specific values of energy levels.	**0.75**
2.1	$E_n - E_1 = \dfrac{h\,c}{\lambda}$ $\dfrac{h\,c}{\lambda} = \left(\dfrac{-122.4}{n^2}\right) - \left(\dfrac{-122.4}{1^2}\right)$; $\dfrac{6.62\times10^{-34}\times3\times10^{8}}{\lambda} = 122.4\times1.6\times10^{-19}\times\left(1-\dfrac{1}{n^2}\right)$ $\lambda = \dfrac{6.62\times10^{-34}\times3\times10^{8}}{122.4\times1.6\times10^{-19}\times\left(1-\dfrac{1}{n^2}\right)}$; $\lambda = \dfrac{0.1014\times10^{-7}}{\left(1-\dfrac{1}{n^2}\right)}$ m $\lambda = \dfrac{0.01014}{\left(1-\dfrac{1}{n^2}\right)}$ µm and n > 1.	**1**
2.2	Maximum wavelength corresponds to n = 2 : so $\lambda_{max} = \dfrac{0.01014}{\left(1-\dfrac{1}{n^2}\right)} = 0.01352$ µm Minimum wavelength corresponds to n = ∞ : so $\lambda_{min} = \dfrac{0.01014}{\left(1-\dfrac{1}{n^2}\right)} = 0.01014$ µm	**1** **1**
3.1	From: $E_3 \rightarrow E_1$; $E_3 \rightarrow E_2$; $E_2 \rightarrow E_1$.	**0.75**
3.2	$E_3 \rightarrow E_1$: $\dfrac{h\,c}{\lambda} = E_3 - E_1$; $\lambda_{3\rightarrow1} = \dfrac{6.62\times10^{-34}\times3\times10^{8}}{108.8\times1.6\times10^{-19}} = 0.11408\times10^{-7}$ m = 0.011408 µm **<u>Or</u>** : $\lambda_{3\rightarrow1} = \dfrac{0.01014}{\left(1-\dfrac{1}{3^2}\right)} = 0.0114075$ µm $E_3 \rightarrow E_2$: $\dfrac{h\,c}{\lambda} = E_3 - E_2$; $\lambda_{3\rightarrow2} = \dfrac{6.62\times10^{-34}\times3\times10^{8}}{17\times1.6\times10^{-19}} = 0.7301\times10^{-7}$ m = 0.07301 µm $E_2 \rightarrow E_1$: $\dfrac{h\,c}{\lambda} = E_2 - E_1$; $\lambda_{2\rightarrow1} = \dfrac{6.62\times10^{-34}\times3\times10^{8}}{91.8\times1.6\times10^{-19}} = 0.1352\times10^{-7}$ m = 0.01352 µm **<u>Or</u>** : $\lambda_{2\rightarrow1} = \lambda_{max} = \dfrac{0.01014}{\left(1-\dfrac{1}{n^2}\right)} = 0.01352$ µm	**1.5**
3.3	Ultraviolet since all wavelengths are less than 0.400 µm	**0.5**