UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

School of Chemistry & Physics
Pietermaritzburg Campus
November 2015: Main Examination: PHYS120
Electricity & Magnetism, Optics, Atomic Physics

Student No.:									
Seat Number:									

BAR CODE

SECTION A Short Questions				**SECTION B** Electromagnetism				**SECTION C** Optics				**SECTION D** Atomic Physics			
	Int	Ext	Max		Int	Ext	Max		Int	Ext	Max		Int	Ext	Max
1–20			60	B1			10	C1			10	D1			10
				B2			10	C2			10	D2			10
				B3			10	C3			10	D3			10
				B4			10								
				B5			10								
				B6			10								
Total			60				60				30				30

GRAND TOTAL	**INT**	**EXT**	**MAX**
			180

Rule 9(1)(e) WARNING: CANDIDATES WILL BE DISQUALIFIED IF:

(a) they introduce, or attempt to introduce, into any place where an examination is about to be conducted or is being conducted, any paper, book, note, document or instrument, the use of which is not authorized by the examiner or the examination officer.

(b) they possess, use, or attempt to use during an examination, any paper, book, note, document or instrument the use of which is not authorized by the examiner or the examination officer.

(c) they remove or attempt to remove from the examination room, any examination book or writing paper supplied by the University for the purposes of answering an examination.

(d) they communicate or attempt to communicate any information relating to the examination to another candidate while the examination is in progress.

(e) they use a false name or identity number in an examination.

(f) they commit any other fraudulent, deceitful or dishonest practice which would mislead or deceive the examiner or examination officer.

IF A STUDENT IS FOUND GUILTY BY A STUDENT DISCIPLINE COURT OF CONTRAVENING THE ABOVE RULE – 9(1)(e) – SHE/HE WILL SUFFER ONE OR MORE OF THE FOLLOWING CONSEQUENCES:

(i) Disqualification from entry to any examination.

(ii) Cancellation or forfeiture of examination results.

(iii) Deprivation of a degree, diploma or certificate obtained as a result of the offence.

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School of Chemistry & Physics
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November 2015: Main Examination: PHYS120
Electricity & Magnetism, Optics, Atomic Physics

TIME: 3 hours **MAXIMUM MARKS:** 180

Internal Examiners	**External Examiner/Moderating Board:**
Dr. A. Welter, Mr. K. Singh, Ms. T. Govindasamy & Mr. M. Mthembu	Dr. S. Mthembu

General instructions

1. Answer ALL questions on the question paper. Pencil may be used provided this is clearly visible. All answers must be in legible handwriting.
2. **It is the candidate's responsibility to ensure that this paper has 21 numbered pages, including the data sheet.**
3. Do your rough work for a question on the back of the previous page. Rough work will not necessarily be marked. See instruction 7 below.
4. The last page of this exam is an information sheet and is printed separately on yellow paper. It may be torn off.
5. Apart from the information sheet, no other part of this exam paper may be torn off.
6. Marks have been allocated in such a way that 1 mark corresponds approximately to one minute. Candidates are advised not to spend a disproportionate amount of time on any question.
7. Should a candidate require more space to answer a question than has been provided, this must be indicated clearly, by, for example, 'PTO' or 'See back of page 7', etc.
8. Where appropriate, candidates are advised to show working for their answers to all questions, and in particular those of Section A.

SECTION A — SHORT QUESTIONS (20 × 3 marks) — 60 MARKS

1. Two identical conducting spheres carrying charges of $-8\,\mu C$ and $12\,\mu C$ are brought into contact. Calculate the amount of charge transferred between the spheres (remember to state +ve or −ve, and from which sphere to which).

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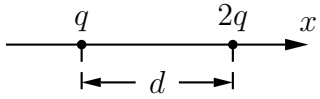
2. Charges q and $2q$ separated by a distance d in vacuum are located on the x axis as shown in the figure alongside. Write down a vector expression for the force $\mathbf{F}$ which charge $2q$ exerts on charge q.



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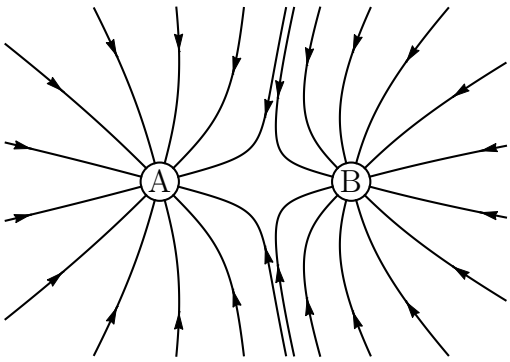
3. The diagram alongside represents the electric field due to two charges A and B. Complete the following sentences:

   (a) The sign of charge A is ..... and the sign of charge B is .....

   (b) The magnitude of charge A is .... the magnitude of charge B.



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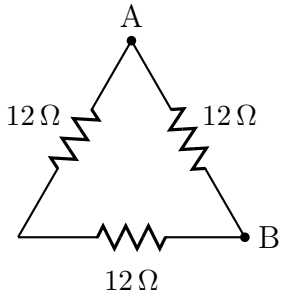
4. Calculate the equivalent resistance between the points A and B shown in the diagram alongside.



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5. What length of copper wire with a cross-sectional area of $2.0\,\text{mm}^2$ will have a resistance of $5.1\,\Omega$? (The resistivity of copper is $1.7 \times 10^{-8}\,\Omega\,\text{m}$).

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6. A 3.7 V mobile telephone battery has an ampere-hour rating of 700 mA h. If a constant current of 200 mA is drawn during a normal conversation, determine how long it will take before the battery will start to run down.

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7. List two significant properties about a series RLC circuit which is at resonance.

   (a) .....

   (b) .....

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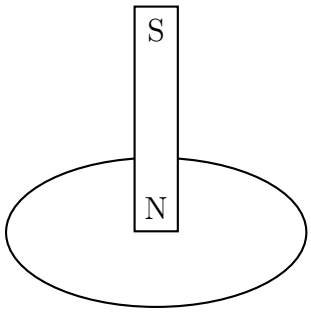
8. A bar magnet approaches the centre of a ring of wire as shown in the diagram.



   (a) Name the law and the rule which will determine the direction of the current induced in the ring.

   .....

   .....

   .....

   (b) On the diagram indicate with an arrowhead the direction of the induced current.

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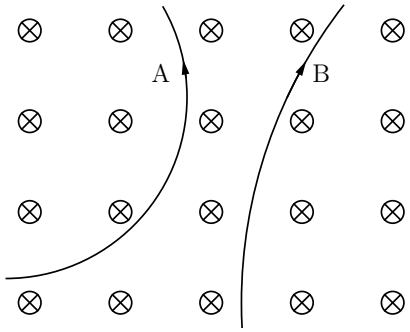
9. The diagram alongside represents two particles moving in a uniform magnetic field. The magnitude of the charge on each particle is the same and the particles have equal mass.



   (a) What is the sign of the charge of particle A?

   (b) What is the sign of the charge of particle B?

   (c) Which particle has the greater speed?

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10. An ideal transformer has 1000 turns on its primary and 100 turns on the secondary.

   (a) Is this a step-up or a step-down transformer?

   (b) If the current drawn in the secondary is 5.0 A rms, what peak current flows in the primary?

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11. A coin at the bottom of a swimming pool appears to lie 1.5 m below the surface where the water is 2.0 m deep. Calculate the refractive index of water relative to air.

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12. (a) When light is transmitted from one medium to another of different refractive index, explain what is meant by the critical angle.

    (b) Find the critical angle for an air-water boundary ($n_{\text{water}} = 1.33$).

---

13. A double convex lens is made of glass which has a refractive index of 1.65. One surface has a radius of curvature of 20 cm and the other has a radius of curvature of 25 cm. Determine the focal length of this lens.

---

14. A sugar solution of concentration $0.13\,\text{g}\,\text{cm}^{-3}$ is found to rotate the plane of vibration of plane polarized light by 50°. What is the length of the tube containing sugar? (Take the specific rotation of sugar as $42.3\,^\circ\,\text{cm}^2\,\text{g}^{-1}$)

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15. Light of wavelength 588 nm, from a point source, passes through two parallel and narrow slits which are 0.5 mm apart. Determine the distance between the central bright fringe and the second bright interference fringe formed on a screen parallel to the plane of the slits and 1.0 m away.

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16. How many protons, neutrons and electrons are there in each of the following atoms:

    (a) $^{3}_{2}\mathrm{He}$: _____ protons; _____ neutrons; _____ electrons.

    (b) $^{12}_{6}\mathrm{C}$: _____ protons; _____ neutrons; _____ electrons.

    (c) $^{206}_{82}\mathrm{Pb}$: _____ protons; _____ neutrons; _____ electrons.

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17. What is the energy of a photon of wavelength 532 nm?

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18. A radioactive substance has a decay constant λ. How long will it take for 30 % of the substance to decay? Express your answer in terms of λ.

---

19. What minimum voltage must be applied to an x-ray tube to generate x rays with a wavelength of $4.0 \times 10^{-10}\,\mathrm{m}$?

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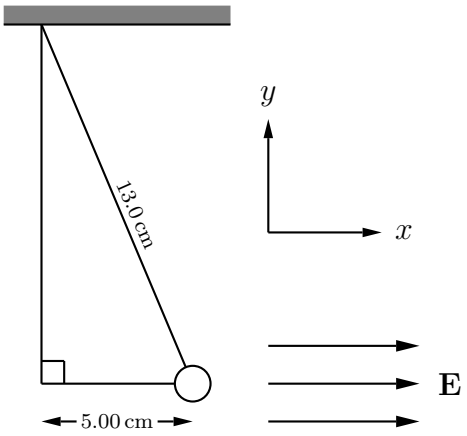
20. The electron in the hydrogen atom makes a transition in the Balmer series from the $n = 3$ to the $n = 2$ energy level. Given that $R = 1.097 \times 10^{7}\,\mathrm{m}^{-1}$, calculate the wavelength of the emitted photon.

/60

SECTION B ELECTRICITY & MAGNETISM 60 MARKS

QUESTION B1

A small, 3.00 g plastic sphere is suspended from a 13.0 cm insulating string of negligible mass. In the presence of a uniform electric field $\mathbf{E} = 4.90 \times 10^3\,\hat{\mathbf{x}}\,\mathrm{N\,C^{-1}}$, the sphere comes to rest as shown in the diagram alongside.



(a) Is the charge on the sphere positive or negative? (1)

(b) Determine the charge on the sphere. (9)

/10

QUESTION B2

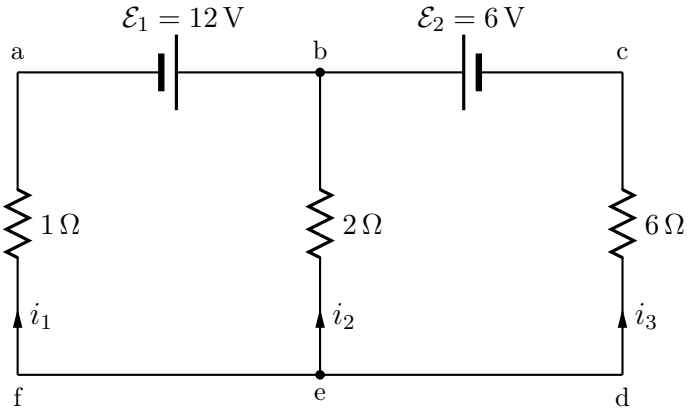
An iron wire has a resistance of 6.2 Ω at 25 °C and an aluminium wire has a resistance of 7.4 Ω at the same temperature. The temperature coefficients of resistance for iron and aluminium are $6.5 \times 10^{-3}\,°C^{-1}$ and $4.4 \times 10^{-3}\,°C^{-1}$ respectively. Assume the resistance of the two wires varies linearly with temperature.

(a) On the axes provided below, sketch labelled graphs of the dependence of resistance on temperature for each of the two wires. Clearly indicate where the wires have the same temperature. (3)

(b) Determine the temperature at which the iron and aluminium wires have the same temperature. (7)

/10

QUESTION B3



With reference to the circuit shown above,

(a) use Kirchhoff's current rule to obtain an equation for the node b. (1)

(b) use Kirchhoff's voltage rule to obtain equations for the loops abefa and bcdeb. (4)

(c) Given that $i_3 = -0.3\,\mathrm{A}$, determine the potential V_d at d relative to the potential V_a at a. Which point, a or d, is at a higher potential? (5)

/10

QUESTION B4

The current in a series RCL circuit ($R = 12\,\Omega$, $C = 2000\,\mu\text{F}$, $L = 100\,\text{mH}$) is

$$i = 5.0\cos(50t)\,\text{A}.$$

(a) Determine the impedance of the circuit. (4)

(b) What is the instantaneous voltage across the RCL combination? (5)

(c) Should a capacitor or an inductor be added to the circuit to increase the power factor? (1)

/10

QUESTION B5

Two long straight parallel wires, separated by 10 cm, carry currents $I_A = 2.0\,A$ and $I_B = 5.0\,A$ in opposite directions.

(a) Will the wires attract or repel each other? (1)

(b) With the aid of a sketch, explain your answer to (a). (3)

(c) Determine the force per unit length wire A exerts on wire B. (3)

(d) Calculate the magnetic field at a point in between the wires, 2.0 cm from wire A, on the line joining the two wires. (3)

/10

QUESTION B6

(a) A thin-walled metal sphere has a radius of 20 cm and carries a charge of 25 nC. Find the electric field **E** for a point

(i) inside the sphere, (1)

(ii) 3.0 m from the centre of the sphere. (4)

(b) A circular coil of 2000 turns and radius 4.0 cm rotates in 0.1 s about a vertical axis from a position where its plane is parallel to a horizontal magnetic field B to a position where it is perpendicular to B. Determine the emf induced in the coil if the magnetic field has magnitude $B = 1.5 \times 10^{-4}$ T. (5)

/10

SECTION C GEOMETRICAL & PHYSICAL OPTICS 30 MARKS

QUESTION C1

A 5.0 cm high object is located 8.0 cm from a double-convex lens, whose focal length is 10 cm.

(a) Determine the height, nature and position of the image by calculation. (5)

(b) If the lens has a refractive index of 1.65, what is the radius of curvature if both surfaces are the same? (2)

(c) Sketch a labelled ray diagram to show how the image is formed. (3)

/10

QUESTION C2

(a) A spherical mirror has a focal length of 10 cm. Locate and describe the image formed for an object placed 25 cm away from the mirror. (5)

(b) (i) In a newton's rings experiment the diameter of the 3rd dark ring is 3.17 mm, what is the diameter of the 10th dark ring? (3)

(ii) If the radius of the Plano-convex lens used in part (i) above is 1.5 m, what is the wavelength of the light being used? (2)

/10

QUESTION C3

(a) When using a diffraction grating, state one advantage of having more slits per unit length. (2)

(b) Monochromatic light wavelength $\lambda = 410\,\text{nm}$ is incident normally on a diffraction grating containing 5000 lines/cm.

(i) Find the angular position of the 2nd and 4th order maxima. (5)

(ii) Are 5th order diffraction maxima possible? Explain. (3)

/10

SECTION D ATOMIC PHYSICS 30 MARKS

QUESTION D1

(a) How many atoms are there in 2 kg of lead if the atomic mass of lead is 207 u? (2)

(b) The mass of the $^{84}_{36}$Kr isotope is 83.9115 u.

(i) Determine its binding energy per nucleon in MeV. (You may assume that $1\,\text{u} \equiv 930\,\text{MeV}$.) (4)

(ii) How many atoms of $^{235}_{92}$U are needed to produce 800 MW of electric power in one day if the fission of one atom of $^{235}_{92}$U produces 185 MeV. (4)

/10

QUESTION D2

(a) Ordinary boron is a mixture of $^{10}_{5}$B and $^{11}_{5}$B isotopes and has a composite atomic mass of 10.82 u. Find the percentage of each isotope present (by mass) in ordinary boron. The atomic masses of $^{10}_{5}$B and $^{11}_{5}$B are 10.01 u and 11.01 u respectively. (3)

(b) The work function of tungsten is 4.49 eV.

(i) Determine the threshold wavelength for photo-emission. (3)

(ii) If ultraviolet light of wavelength 250 nm falls on the surface, calculate the maximum energy of the emitted electrons in eV. (3)

(iii) What potential difference is required to bring all the ejected electrons in (ii) above to rest? (1)

/10

QUESTION D3

(a) If the series limit for the Balmer series lies at 3648 Å, calculate the wavelengths of the first members of the Lyman and Paschen series. (Work in Å.) (4)

(b) (i) Show that the number of radioactive nuclei N remaining after time t is given by

$$N = N_0 e^{-\lambda t},$$

where N_0 is the initial number of atoms present and λ is the decay constant. (4)

(ii) Hence show that the half-life T is given by

$$T = \frac{\ln 2}{\lambda} \quad (2)$$

/10

INFORMATION SHEET

PHYSICAL CONSTANTS

$c = 3.00 \times 10^8\,\mathrm{m\,s^{-1}}$ $\quad n_{\mathrm{air}} = 1.00$ $\quad g = 9.80\,\mathrm{m\,s^{-2}}$

$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$ $\quad m_p \simeq m_n = 1.67 \times 10^{-27}\,\mathrm{kg}$ $\quad e = 1.60 \times 10^{-19}\,\mathrm{C}$

$m_e = 0.000\,55\,\mathrm{u}$ $\quad m_p = 1.0073\,\mathrm{u}$ $\quad m_n = 1.0087\,\mathrm{u}$

$N_{\mathrm{A}} = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$ $\quad h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$

$\dfrac{1}{4\pi\varepsilon_0} = 9.00 \times 10^9\,\mathrm{N\,m^2\,C^{-2}}$ $\quad \dfrac{\mu_0}{2\pi} = 2.00 \times 10^{-7}\,\mathrm{T\,m\,A^{-1}}$

ELECTRICITY & MAGNETISM

$\mathbf{F} = q\mathbf{E}$ $\quad j = \dfrac{i}{A} = nev$ $\quad \psi = \dfrac{Q_{\mathrm{net}}}{\varepsilon_0}$ $\quad \psi = EA\cos\theta$ $\quad \mathbf{F} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}\hat{\mathbf{r}}$

$E = \dfrac{V}{d}$ $\quad \dfrac{1}{C_{\mathrm{eq}}} = \sum_i \dfrac{1}{C_i}$ $\quad V = \mathcal{E} - Ir$ $\quad R = \rho\dfrac{\ell}{A}$ $\quad \mathbf{E} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}\hat{\mathbf{r}}$

$R = \dfrac{V}{I}$ $\quad C_{\mathrm{eq}} = \sum_i C_i$ $\quad V = L\dfrac{di}{dt}$ $\quad W = \dfrac{1}{2}qV$ $\quad V = \dfrac{1}{4\pi\varepsilon_0}\sum_n \dfrac{q_n}{r_n}$

$C = \dfrac{q}{V}$ $\quad \dfrac{1}{R_{\mathrm{eq}}} = \sum_i \dfrac{1}{R_i}$ $\quad X_L = \omega L$ $\quad X_C = \dfrac{1}{\omega C}$ $\quad U = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r}$

$V = \dfrac{W}{q}$ $\quad R_{\mathrm{eq}} = \sum_i R_i$ $\quad \omega_0 = \dfrac{1}{\sqrt{LC}}$ $\quad \phi = BA\cos\theta$ $\quad q = \mathcal{E}C\left(1 - e^{-t/\tau}\right)$

$\tau = RC$ $\quad i = i_0\cos\omega t$ $\quad q = q_0 e^{-t/\tau}$ $\quad B = \dfrac{\mu_0}{2\pi}\dfrac{I}{r}$ $\quad \oint_C \mathbf{B}\cdot d\boldsymbol{\ell} = \mu_0 I_{\mathrm{net}}$

$P = VI$ $\quad \dfrac{V_{\mathrm{s}}}{V_{\mathrm{p}}} = \dfrac{n_{\mathrm{s}}}{n_{\mathrm{p}}}$ $\quad \mathcal{E} = -\dfrac{d\phi}{dt}$ $\quad F = BI\ell\sin\theta$ $\quad R_T = R_0(1 + \alpha T)$

$i = \dfrac{dq}{dt}$ $\quad F = qvB\sin\theta$ $\quad B = \mu_0 nI$ $\quad \dfrac{F}{\ell} = \dfrac{\mu_0}{2\pi}\dfrac{I_1 I_2}{L}$ $\quad \tan\alpha = \dfrac{X_L - X_C}{R}$

$V_{\mathrm{AB}} = V_{\mathrm{B}} - V_{\mathrm{A}} = -\int_{\mathrm{A}}^{\mathrm{B}} E dr$ $\quad \langle P\rangle = V_{\mathrm{rms}} I_{\mathrm{rms}}\cos\alpha$ $\quad Z = \sqrt{R^2 + (X_L - X_C)^2}$

GEOMETRICAL & PHYSICAL OPTICS

$y_n = \dfrac{n\lambda x}{d}$ $\quad a\sin\theta_n = n\lambda$ $\quad 2\mu t = n\lambda$ $\quad d\sin\theta_n = n\lambda$ $\quad r_n^2 = nR\lambda$

$n = \tan\theta_{\mathrm{B}}$ $\quad n = \dfrac{1}{\sin C}$ $\quad \dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f}$ $\quad \dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f} = \dfrac{2}{r}$ $\quad \dfrac{1}{F} = \dfrac{1}{f_1} + \dfrac{1}{f_2}$

$n = \dfrac{\sin\frac{1}{2}(A + D_m)}{\sin\frac{1}{2}A}$ $\quad n_1\sin\theta_1 = n_2\sin\theta_2$ $\quad n = \dfrac{\text{real depth}}{\text{apparent depth}}$

$m = +\dfrac{v}{u} = +\dfrac{i}{o}$ $\quad \dfrac{1}{f} = (n-1)\left(\dfrac{1}{R_1} + \dfrac{1}{R_2}\right)$

ATOMIC PHYSICS

$E = mc^2$ $\quad E_k = \frac{1}{2}mv^2$ $\quad \ell = \dfrac{nh}{2\pi}$ $\quad E_n = -\dfrac{me^4}{8\varepsilon_0^2 h^2}\cdot\dfrac{1}{n^2}$ $\quad F = \dfrac{mv^2}{r}$

$E = hf$ $\quad eV = hf_{\max}$ $\quad N = N_0 e^{-\lambda t}$ $\quad q = \dfrac{6\pi\eta r}{E}(v_{\mathrm{G}} + v_{\mathrm{E}})$ $\quad F = 6\pi\eta r v$

$A = \lambda N$ $\quad n\lambda = 2d\sin\theta_n$ $\quad T = \dfrac{\ln 2}{\lambda}$ $\quad \frac{1}{2}mv_{\max}^2 = hf - \phi$ $\quad r_n = \dfrac{h^2\varepsilon_0}{\pi me^2}n^2$

$\lambda = \dfrac{h}{p}$ $\quad A = A_0 e^{-\lambda t}$ $\quad E_i - E_f = hf$ $\quad \dfrac{1}{\lambda} = R\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$