Section A: 多選題（第1題至第12題，每題有5個選項，其中至少有一個是正確的選項，請將正確選項畫記在答案卡之「選擇題答案區」。各題之選項獨立判定，所有選項均答對者，得5分；答錯1個選項者，得3分；答錯2個選項者，得1分；答錯多於2個選項或所有選項均未作答者，該題以零分計算。）Additional information in the Appendix may be useful for answering the questions.

1. The electrical conductivity of silver is 6.2×10^7 $(\Omega \cdot m)^{-1}$. There is a silver wire having a diameter of 100 μm and a length of 10 cm. Find all the range(s) of the electrical resistance (R) of the wire.
   (a)$10^{-2}\,\Omega < R < 1\,\Omega$. (b)$10^{-1}\,\Omega < R < 10\,\Omega$. (c)$1\,\Omega < R < 100\,\Omega$. (d)$10\,\Omega < R < 1000\,\Omega$.
   (e)$100\,\Omega < R < 10000\,\Omega$. (5 points)

2. A silicon specimen is a cylindrical rod with a 5.0-mm diameter and a 50 mm length. There is a current of 100 mA passing in an axial direction. A voltage of 12.5 V is measured across two probes that separated by 38 mm. Choose all the correct answer(s) for the electrical conductivity (σ) of the specimen. (a)$10^{-2}\,(\Omega \cdot m)^{-1} < \sigma < 1\,(\Omega \cdot m)^{-1}$. (b)$10^{-1}\,(\Omega \cdot m)^{-1} < \sigma < 10\,(\Omega \cdot m)^{-1}$.
   (c)$1\,(\Omega \cdot m)^{-1} < \sigma < 100\,(\Omega \cdot m)^{-1}$. (d)$10\,(\Omega \cdot m)^{-1} < \sigma < 1000\,(\Omega \cdot m)^{-1}$.
   (e)$100\,(\Omega \cdot m)^{-1} < \sigma < 10000\,(\Omega \cdot m)^{-1}$. (5 points)

3. There are five wires made of Ag, Al, Au, Cu, and Ni, respectively. Each wire has the same length (1 m), and the same resistance (1 kΩ). Among the five metal wires, find the three wires having the higher weights: (a)Ag (b)Al (c)Au (d)Cu (e)Ni. (5 points)

4. There are five wires made of Ag, Al, Au, Cu, and Ni, respectively. Each wire has the same length (1 m), and the same diameter (0.1 mm). All the five wires are connected in parallel to a 12.5 V voltage source. Find the two wires having higher temperature: (a)Ag (b)Al (c)Au (d)Cu (e)Ni. (5 points)

5. Liquid nitrogen (LN) is nitrogen in a liquid state that can be held at 77 K. Find all the correct description(s) for the materials' conductivity at LN temperature, compared to that at room temperature. (a)Germanium will have higher electrical conductivity at LN temperature. (b)Germanium will have lower electrical conductivity at LN temperature. (c)Silver will have higher electrical conductivity at LN temperature. (d) Silver will have lower electrical conductivity at LN temperature. (e) Germanium will have the same electrical conductivity at both temperatures. (5 points)

6. Lead telluride (PbTe) is a compound semiconductor composed of lead and tellurium. At room temperature the electrical conductivity of PbTe is 550 $(\Omega \cdot m)^{-1}$, whereas the electron and hole mobilities are 0.16 and 0.08 $m^2/V \cdot s$, respectively. Choose all the correct answer(s) for the carrier concentration (n) in the PbTe crystal at room temperature. (a)$10^{15}\,m^{-3} < n < 10^{19}\,m^{-3}$.
   (b)$10^{17}\,m^{-3} < n < 10^{21}\,m^{-3}$. (c)$10^{19}\,m^{-3} < n < 10^{23}\,m^{-3}$. (d)$10^{21}\,m^{-3} < n < 10^{25}\,m^{-3}$.
   (e)$10^{23}\,m^{-3} < n < 10^{27}\,m^{-3}$. (5 points)

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7. Cuprous oxide (Cu_2O) is a semiconductor with direct bandgap of 2.14 eV, while silicon (Si) is another semiconductor with indirect bandgap of 1.12 eV, at room temperature. Find all the correct description(s) assuming all the crystals having negligible impurities and defects. (a)The electron density in the Cu_2O is lower than the electron density in the Si. (b)The electron density in the Cu_2O is higher than the electron density in the Si. (c)Cu_2O crystal is transparent at 600 nm. (d)Si crystal is transparent at 600 nm. (e)Both crystals are suitable for light-emission applications. (5 points)

8. The macroscopic magnetic properties of the materials are a consequence of their magnetic moments associated with individual electrons. Each electron in an atom has magnetic moments that originate from two sources. One is related to its orbital magnetic moments, and the other is related to its spin magnetic moments. The net magnetic moment of an atom is the vector sum of its orbital and spin magnetic moments. Find the correct description(s) of the individual atoms in gas phase. (a) $_{47}$Ag atom is diamagnetic. (b) $_{47}$Ag atom is paramagnetic. (c) $_{10}$Ne atom is diamagnetic. (d) $_{10}$Ne atom is paramagnetic. (e) $_1$H atom is diamagnetic. (5 points)

9. Two silicon crystals (crystal A and B) both have the same concentration of phosphorus (P) impurity $\left(1.2 \times 10^{16} \text{ m}^{-3}\right)$. However, crystal B is further doping with boron (B) impurity of 1.0×10^{16} m^{-3} concentration. Find all the correct answer(s). (a) Both crystals are p-type semiconduction. (b) Both crystals are n-type semiconduction. (c) One crystal is n-type, while the other one is p-type. (d)The carrier concentration in crystal A is higher than that in crystal B at room temperature. (e) The carrier concentration in crystal A is lower than that in crystal B at room temperature. (5 points)

10. A hydrogen atom is an electrically neutral atom containing a single positively charged proton and a single negatively charged electron bound to the nucleus by the Coulomb force. Assume that the separation between the proton and the electron is 5.3×10^{-11} m, choose all the correct description(s) for the attraction force (F) between the proton and electron in a hydrogen atom.
(a)10^{-5}N > F > 10^{-8}N. (b)10^{-6}N > F > 10^{-9}N. (c)10^{-7}N > F > 10^{-10}N. (d)10^{-8}N > F > 10^{-11}N.
(e)10^{-9}N > F > 10^{-12}N. (5 points)

11. DVD (an abbreviation of "digital video disc") is a digital optical disc storage format invented and developed by Philips, Sony, Toshiba, and Panasonic in 1995. The laser diode used in DVD is a red laser with 650 nm wavelength. Choose all the correct answers for the laser light. (a) Its photon energy is higher than 1.8 eV. (b) Its photon energy is less than 1.8 eV. (c) The optical frequency is larger than 5×10^{14} Hz. (d) The optical frequency is less than 5×10^{14} Hz. (e) The optical frequency is equal to 5×10^{14} Hz. (5 points)

12. A capacitor is a passive two-terminal electrical component used to store energy electrostatically in an electric field. There is a parallel-plate capacitor having area of 100 cm^2 and spacing of 1 mm, which is applied a voltage of 10 V in between. Find the correct answer(s) of the density of the charge (Q) stored in the capacitance. (a)$10^7 e/\text{m}^2 < Q < 10^9 e/\text{m}^2$. (b)$10^8 e/\text{m}^2 < Q < 10^{10} e/\text{m}^2$.
(c)$10^9 e/\text{m}^2 < Q < 10^{11} e/\text{m}^2$. (d) $10^{10} e/\text{m}^2 < Q < 10^{12} e/\text{m}^2$. (e) $10^{11} e/\text{m}^2 < Q < 10^{13} e/\text{m}^2$. (5 points)

Section B: 非選擇題: 答案必須寫在「答案卷」上，並於題號欄標明大題號（13、14、15）與子題號（a、b）。作答時不必抄題，但必須寫出計算過程或理由，否則將酌予扣分。

13. There is a pure metal "A" with a density of 10.0 g/cm³ . At room temperature, the electrical conductivity and the electron mobility of metal A are 5.0×10^7 $(\Omega \cdot m)^{-1}$ and 0.0050 m²/V·s, respectively. Assuming all the electrical conductivity is contributed by the free electrons in the metal. (a)(8 points) Compute the number of free electrons per cubic meter for the metal A at room temperature. (b)(8 points) What is the number of free electrons per atom of the metal A? (sub-total 16 points)

14. Fermat's principle is the principle that the path taken between two points by a ray of light is the path that can be traversed in the least time. Displayed in Fig. 1, the path taken by light in going from some point A to a point B via a reflecting mirror surface. Assume that the path passing point "O" on the mirror is the shortest possible one. The distance between point A and the mirror is a, while that between point B and the mirror is b. The vertical distance between A and O is set as x. Derive the Law of Reflection using Fermat's principle. (10 points)

Fig. 1
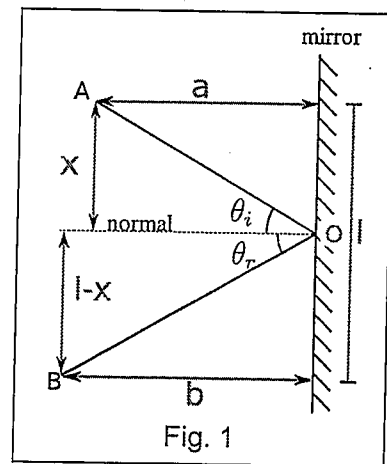
15. There is a green He-Ne laser with wavelength 543 nm, optical power 2.0 mW, and laser beam diameter of 0.83 mm. (a)(6 points) What is the photon energy (in eV) of the laser light? (b)(8 points) What is the photon flux ($\frac{\text{\# of photons}}{m^2 \cdot s}$) of the laser beam? (sub-total 14 points)

Appendix: The following information may be useful for answering the questions.

➢ The permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12} \dfrac{C^2}{N \cdot m^2} = 8.85 \times 10^{-12} \dfrac{F}{m}$

➢ The electric charge carried by a single electron $e = 1.602 \times 10^{-19} C$.

➢ Planck constant $h = 6.626 \times 10^{-34} J \cdot s = 4.136 \times 10^{-15} eV \cdot s$

➢ The speed of light in a vacuum $c = 299792458 \ m/s$

➢ The Avogadro constant $N_A = 6.022 \times 10^{23} \ mol^{-1}$.

Table 1: Electrical conductivity (σ), density (g/cm³), and atomic weight (g/mole) for some metals

Material	$\sigma \ (\Omega \cdot m)^{-1}$	(g/cm³)	(g/mole)
Aluminum	3.5×10^7	2.70	26.98
Beryllium	2.8×10^7	1.85	9.012
Copper	6.0×10^7	8.96	63.55
Gold	4.1×10^7	19.3	196.97
Iron	1.0×10^7	7.87	55.85
Magnesium	0.21×10^7	1.74	24.31
Nickel	1.4×10^7	8.90	58.69
Silver	6.2×10^7	10.5	107.87
Tungsten	1.8×10^7	19.3	183.84
Zinc	1.7×10^7	7.00	65.38

Table 2: Dielectric constants and strengths for some dielectric materials

Materials	Dielectric constant		Dielectric strength (V/2.5mm)
	60 Hz	1 MHz	
Fused silica	4.0	3.8	250
Mica	8.7	5.4	1000 – 2000
Nylon 6,6	4.0	3.6	400
Polystyrene	2.6	2.6	500 – 700
Soda-lime glass	6.9	6.9	250