General Physics II: Term Exam (113–2)

100 minutes, full mark = 50

Use of your notebooks/memos/books:	One tiny sheet is allowed.
Use of your mobile etc. & Internet:	Strictly forbidden.
Discussion with other attending students:	Strictly forbidden.

Administrative Remarks

- Write your name and student ID on the answer sheet. Put your student ID on the desk.
- Allowed on your desk: student ID card (required), pens/pencils, correction tools (eraser etc.), rulers, a "cheat sheet" not larger than student ID card, and drinks. **Other items must be stored in your bags.**
- You cannot wear watches nor electronic devices. **You cannot have them even in your pockets**.
- **After 9:10, the following actions are considered cheating. You may immediately lose your credit.**
  - If non-allowed items (pen cases, foods, poaches, etc.) are found on desks.
  - If you have textbooks, mobile phones, tablets, or PC, if they are not stored in your bags, or if you use them. They must be in your bags even after you submit your answer sheets.
- Breaks are not allowed in principle. After 10:00, you may leave after submission. In case of health problems or other issues, call the TA or lecturer.
- *Any form of academic dishonesty, including chats, additions/corrections after the period, and using your phones, will be treated by NSYSU "Academic Regulations."*

Scientific Remarks

- Show your calculations or thought process for **partial mark**!
- Use English, where mistakes are tolerated. Meanwhile, scientific mistakes are not tolerated.
  - Provide appropriate **units** properly. Handle **significant digits** properly.
  - Clearly distinguish **vectors** (by writing $\vec{E}$, $\vec{x}$ or $\mathbb{E}$, $\mathbb{x}$) from scalars (E, x).
- If you find any errors or issues in the questions, explain them on your answer sheet, make necessary adjustments on the question, and answer accordingly.
- You may use the following symbols and values without definition/declaration.

standard acceleration of gravity	g	$= 9.8\,\mathrm{m/s^2}$
Newtonian constant of gravitation	G	$= 6.7\times10^{-11}\,\mathrm{N\cdot m^2/kg^2}$
elementary charge	e (or $\lvert e\rvert$)	$= 1.6\times10^{-19}\,\mathrm{C}$
permittivity of free space	ϵ_0	$= 8.9\times10^{-12}\,\mathrm{C^2\,N^{-1}\,m^{-2}}$
permeability of free space	$\mu_0 = \left(\epsilon_0 c^2\right)^{-1}$	$= \pi\times4.0\times10^{-7}\,\mathrm{N/A^2}$
Coulomb constant	$k_e = \left(4\pi\epsilon_0\right)^{-1}$	$= 9.0\times10^{9}\,\mathrm{N\cdot m^2/C^2}$
speed of light in vacuum	c	$= 3.0\times10^{8}\,\mathrm{m/s}$
Avogadro's number	N_A	$= 6.0\times10^{23}/\mathrm{mol}$
masses of protons and electrons	m_p, m_e	$= 1.7\times10^{-27}\,\mathrm{kg}, 9.1\times10^{-31}\,\mathrm{kg}$

Unit vectors in the direction of the axes $(\vec{e_x}, \vec{e_y}, \vec{e_z})$ or $(\hat{e_x}, \hat{e_y}, \hat{e_z})$ or $(\hat{\imath}, \hat{\jmath}, \hat{k})$

$\vec{E}(\vec{x})$	electric field at $\vec{x}$	$\vec{B}(\vec{x})$	magnetic field (magnetic flux density) at $\vec{x}$
$V(\vec{x})$	electrostatic potential at $\vec{x}$	$\vec{F}_{XY}$	force exerted by X on Y

$\sqrt{2}\approx1.414$ $\quad\sqrt{3}\approx1.732$ $\quad\sqrt{5}\approx2.236$ $\quad\sqrt{7}\approx2.646$ $\quad\pi\approx3.142$ $\quad\mathrm{e}\approx2.718$

Answer all the problems.

[Part I] Fundamental concepts (12 points)

(A) For each of the following physical quantities, write its unit.

1) wavelength	**4)** electric field	**7)** capacitance
2) permeability	**5)** magnetic field	**8)** inductance
3) power	**6)** magnetic flux	**9)** resistance

(B) Fill the blanks (1)–(7).

The equation $E(x,t) = E_{\max}\cos[2\pi(x/\lambda - ft)]$ and $B(x,t) = B_{\max}\cos[2\pi(x/\lambda - ft)]$ describe an electromagnetic wave. Here, f is the __(1)__ and λ is the __(2)__. The speed of this wave is given by $v = f\lambda$, but it is always constant, 3.0×10^8 m/s, in vacuum.

Electromagnetic waves with various f and λ are found. Wi-fi communication uses those with $f = 5.0\,\text{GHz}$ (i.e., $\lambda =$ __(3)__), which is usually categorized in radio waves or microwaves. Medical hair-removal uses Nd:YAG laser with $\lambda = 1.1\,\text{nm}$ (i.e., $f =$ __(4)__); it is categorized in __(5)__. Electromagnetic waves with very small λ, typically $\lambda \lesssim 10^{-11}$ m, are categorized in, or called, __(6)__. They produce serious damage to living tissues and even cause humans' death, which we have witnessed in military conflicts and accidents at __(7)__.

(C) What does it mean that light is a transverse wave? Explain.
[Note: The discussion should be related to the first paragraph of the above text.]

[Part II] Magnetic field (16 points)

Consider two infinitely-long wires, which we call Wire A and Wire B, respectively. They are set parallel and separated by a distance d. Wire A carries an electric current I_A and Wire B carries I_B; the currents are in the same direction.

(A) Find the magnitude of the magnetic field generated due to I_A at the location of Wire B.

(B) Wire B feels a force due to the magnetic field. Find the *magnitude per unit length* of the force.

(C) Describe the direction of the force on Wire B.

(D) If the *magnitude per unit length* of the force is 2.00×10^{-7} N and $I_A = I_B = 1.00\,\text{A}$, what is d?

This is fundamentally explained by the four Maxwell's equations, or in particular, the Ampère-Maxwell law.

(E) Write down the equation describing the Ampère-Maxwell law. It should contain a term $\mu_0 I$, where μ_0 is the permeability of free space and I describes electric current.

(F) I in the term $\mu_0 I$ has a certain specification. Explain the specification of I.

[The exam questions continue on the next page.]

[Part III] Gauss's law (5 points)

A small solid sphere with a radius 1.00 mm, made by a conductor, has a charge 3.14 mC. Its center is at the origin O(0, 0, 0) and no other charges are nearby.

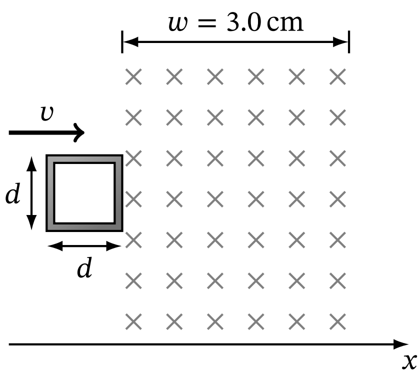
(A) Describe *quantitatively* how the electric charge distributes over the sphere.

Now, imagine a cube of edge 2.0 m whose center is at the origin. We discuss the electric flux through the imaginary cube, where you can use $\epsilon_0 \approx 8.9 \times 10^{-12}\,\mathrm{C^2\,N^{-1}\,m^{-2}}$ and $3.14/8.9 \approx 0.35$.

(B) Find the electric flux through each face of the cube.

(C) Find the electric flux through the whole surface of the cube.

[Part IV] Kinematics of charged particles (17 points)



A square metallic loop moves toward the $+x$ direction with a constant speed $v = 1.0\,\mathrm{cm/s}$ as in the right figure. The loop passes through a uniform magnetic field $\vec{B}$ directed into the sheet with $|\vec{B}| = 0.50\,\mathrm{T}$, which extends a distance $w = 3.0\,\mathrm{cm}$ along the x-axis.

The loop, square-shaped, has a side length $d = 1.0\,\mathrm{cm}$ and the resistance $R = 0.010\,\Omega$. Therefore, it takes 4.0 s to pass through the magnetic field region: at $t = 0$, its right edge enters the magnetic field region, and at $t = 4.0\,\mathrm{s}$, its left edge exits the magnetic field region.

(A) The loop is made of a wire with a cross-sectional area of $0.400\,\mathrm{mm}^2$. Find the resistivity of the material used for the wire.

We are to discuss the magnetic flux through the loop, $\Phi_B(t)$, as a function of time t, but here, to simplify the discussion, we focus on its magnitude, $|\Phi_B(t)|$.

(B) Find $|\Phi_B(t)|$ at $t = 0$, $t = 0.50\,\mathrm{s}$, and $t = 2.0\,\mathrm{s}$. Also, draw a plot of $|\Phi_B(t)|$ for $0 \le t \le 5.0\,\mathrm{s}$.

Similarly, we discuss the current flow $I(t)$ in the loop during $0 \le t \le 5.0\,\mathrm{s}$. The current is zero during certain interval(s) and nonzero during others, where we also want to know its direction.

(C) For $0 \le t \le 5.0\,\mathrm{s}$, determine the time interval(s) during which $I = 0$ and those during which $I \ne 0$. For each interval with $I \ne 0$, also explain the direction of the current.

(D) Find $|I(t)|$ at $t = 0.50\,\mathrm{s}$ and $t = 2.0\,\mathrm{s}$. Also, draw a plot of $|I(t)|$ for $0 \le t \le 5.0\,\mathrm{s}$.

[Part V] Extra Problem

This is a challenging problem but a qualitative discussion is not very difficult. You are encourage to give some qualitative discussion for a partial mark.

A proton under a uniform magnetic field $\vec{B}$ experiences a helical motion. Explain why, and describe the motion in detail.

[Hint: First, assume $\vec{B}$ is in $+z$ direction and specify the initial velocity $\vec{v}(0)$ of the proton. Then, find the force acting on the proton, write down the equation of motion, and solve it.]

[This is the end of the exam questions.]

General Physics II: Note added on the term exam

- In Part I (B), the wavelength of Nd:YAG laser was incorrectly given and it should be 1.1 μm corresponding to 2.8 THz infrared waves. Accordingly, the two blanks about Nd:YAG laser are omitted from the exam and all answers are marked correct. This was announced during the exam.
- In Part II (D), the magnitude per unit length of the force had an incorrect unit and it should be given as 2.00×10^{-7} N/m. No remedies are given but bonus points are given to those who point out this problem on their answer sheet.