# General Physics II: Term Exam (114–2)

**100 minutes, full mark = 50**

It is **strictly forbidden** to use your notebooks/memos/books except for one tiny "cheat sheet".
It is **strictly forbidden** to **have/wear/use** any electric devices, even in your pockets.
It is **strictly forbidden** to discuss with other students.

### Administrative Remarks

- Use full-sized sheets for your answers. Smaller sheets are for calculation, not to submit.
- Write your name and student ID on the answer sheet. Put your student ID on the desk.
- Allowed on desk: student ID card (required), pens/pencils, correction tools (eraser etc.), rulers, a "cheat sheet" not larger than student ID, and drinks. **Others must be stored in your bags.**
- You cannot wear watches nor electronic devices. **You cannot have them even in your pockets**.
- **After 13:10, 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 14:00, 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.
  - 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 | $g$ | $= 9.8\,\mathrm{m/s^2}$ |
| elementary charge | $e$ (or $\lvert e\rvert$) | $= 1.6\times10^{-19}\,\mathrm{C}$ |
| permittivity of free space | $\epsilon_0$ | $= 8.9\times10^{-12}\,\mathrm{C^2\,N^{-1}\,m^{-2}}$ |
| 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 | $N_{\mathrm{A}}$ | $= 6.0\times10^{23}/\mathrm{mol}$ |
| 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] Maxwell's equations (15 points)

Electromagnetism is described by Maxwell's equations, which are given by, in integral form,

Ⓐ $\oint_S \vec{E} \cdot \mathrm{d}\vec{A} = \frac{q}{\epsilon_0}$,

Ⓑ $\oint_C \vec{E} \cdot \mathrm{d}\vec{s} = -\frac{\mathrm{d}}{\mathrm{d}t}\Phi_B$,

Ⓒ $\oint_S \vec{B} \cdot \mathrm{d}\vec{A} = 0$,

Ⓓ $\oint_C \vec{B} \cdot \mathrm{d}\vec{s} = \mu_0 I + \mu_0\epsilon_0\frac{\mathrm{d}}{\mathrm{d}t}\Phi_E$.

Answer the following questions about these equations.

**(A)** The following laws/facts are closely related to the four equations Ⓐ–Ⓓ. For each statement, choose one equation that is **most closely** related to it.

**1)** A charged particle is a source of an electric field.

**2)** An electric current is a source of a magnetic field.

**3)** We can define electric potential if the system is static.

**4)** Faraday's law.

**(B)** Each of the following laws/concepts is closely related to **two** of Ⓐ–Ⓓ. For each law/concept, choose **two equations** that are **most closely** related to it.

**1)** Light. **2)** Biot-Savart law. **3)** Mutual inductance.

**(C)** Write the units of the following quantities appearing in the equations.

**1)** $\vec{B}$. **2)** $\mathrm{d}\vec{s}$ **3)** $\vec{E} \cdot \mathrm{d}\vec{A}$. **4)** Magnetic flux.

**(D)** Explain the meaning of $q$ in Ⓐ, using the phrase "closed surface $S$".

**(E)** Explain the meaning of $\Phi_E$ in Ⓓ, using the phrase "closed loop $C$".

## [Part II] Magnetic field (7 points)

Consider two infinitely-long wires, which we call Wire A and Wire B, respectively. They are set parallel and separated by a distance $d = 1.00\,\mathrm{m}$. Wire A carries an electric current $I_\mathrm{A} = 1.00\,\mathrm{A}$ and Wire B carries $I_\mathrm{B} = 2.00\,\mathrm{A}$; the currents are in the opposite direction.

**(A)** Find the magnetic field generated due to $I_\mathrm{A}$ at the location of Wire B.
[Hint: You need to explain the direction in English, as well as the magnitude.]

**(B)** Wire B feels a force due to the magnetic field. Consider a 10.0 cm-segment of Wire B, i.e., a segment with length $\Delta L = 0.100\,\mathrm{m}$. Find the force acting on the segment.
[Hint: You need to explain the direction in English, as well as the magnitude.]

*[The exam questions continue on the next page.]*

## [Part III] Fundamental Concepts (14 points)

Read the following text and answer the questions below.

> The symbol $I$ in Ampère–Maxwell law means an $\boxed{\textbf{(1)}}$; it is given by $I = |\vec{J}|A$, where $\vec{J}$ is called the $\boxed{\textbf{(2)}}$ and $A$ is the area considered. In conductors, we can describe $\vec{J} = nq\vec{v_\mathrm{d}}$, where $n$ is the $\boxed{\textbf{(3)}}$ of $\boxed{\textbf{(4)}}$, $q$ is the electric charge of each of them, and $\vec{v_\mathrm{d}}$ is called the $\boxed{\textbf{(5)}}$.
>
> Even if $I = 0$ and $q = 0$, where $q$ is the charge in the space, there can be $\vec{B}$ and $\vec{E}$ propagating in the space. This is called light, or an $\boxed{\textbf{(6)}}$. From Maxwell's equations, we can find that it has a speed of $c = \boxed{\textbf{(7)}} \approx 3 \times 10^8$ m/s.
>
> Light is classified into various types. For example, $\boxed{\textbf{(8)}}$ is emitted by warm objects such as human body and detected by automatic door sensors. $\boxed{\textbf{(9)}}$ may cause sunburn, and can be used in sanitization, i.e., to kill germs.

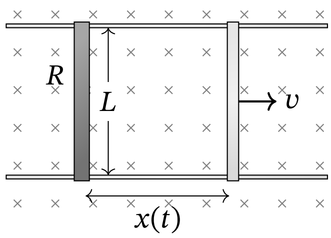
**(A)** Fill the blanks. Blanks other than **(7)** must be filled with **two or more** words, while **(7)** should be filled with a mathematical expression containing $\mu_0$ and $\epsilon_0$.

**(B)** **1)** What is the the typical <u>wavelength</u> and <u>frequency</u> of visible light?

**2)** Microwave oven typically uses light with the frequency of 2.45 GHz. What is the wavelength of this light?

**(C)** Describe the definition of $\vec{v}_\mathrm{d}$, preferably using a mathematical expression.

## [Part IV] Dynamic system (14 points)




As shown in the figure, two rods are placed on two parallel horizontal rails separated by a distance $L$. They are frictionless and have negligible mass and electrical resistance. Each end of the rods always remains in contact with a rail, and the rods are always remain perpendicular to the rails.

The rods are cylindrical, each having radius $d$ and length $L$, but they are made of different metal. The left rod has mass $M$ and resistance $R$, while the right rod has mass $m$ and negligible resistance. The left rod is fixed to the wires with rubber bands, so it cannot move. A uniform magnetic field $\vec{B}$ is applied perpendicular to the system, directed into the sheet.

Let $x(t)$ denote the distance between the rods at time $t$, and define $x_0 = x(0)$. An agent pulls the right rod rightward with a constant speed $v$ from $t = 0$ to $t = t_1$, and at $t = t_1$, she releases the right rod with the speed $v$.

**(A)** Find the mass density and conductivity of the <u>left</u> rod, in terms of $M$, $R$, $L$, and $d$.

**(B)** Find the voltage difference between the two rails, $\Delta V$, between $t = 0$ and $t = t_1$.

**(C)** Find the Lorentz force exerted on the right rod between $t = 0$ and $t = t_1$.

**(D)** Find the energy consumed in the left rod from $t = 0$ to $t = t_1$.

**(E)** Discuss the motion of the right rod after $t = t_1$. In particular, find $x(t)$ as a function of $t > 0$.

*[The exam questions continue on the next page.]*

## [Part V] Extra Problem 1

Discuss the motion of an electron under a uniform magnetic field.

## [Part VI] Extra Problem 2

**(A)** Consider the set up given in **[Part II]** of this exam. Suddenly the electricity supply becomes unstable at $t = 0$ and the currents in Wire A decreases with time, as $I_{\mathrm{A}} = 1.00\,\mathrm{A} - 0.100\,t\,\mathrm{A/s}$ and stay zero after $t > 10.0\,\mathrm{s}$. What will happen? Describe as much as you can.

**(B)** Consider the set up given in **[Part IV]** of this exam. If the left rod is not fixed by the rubber band and can move freely on the rails, but the agent does the same things as described there, what will happen? Discuss anything as much as you can.

*[This is the end of the exam questions.]*