DELFT UNIVERSITY OF TECHNOLOGY
Faculty of Aerospace Engineering

Course: Physics (AE1241)	**Date:** Monday 26 June 2023, 13.30-16.30 h

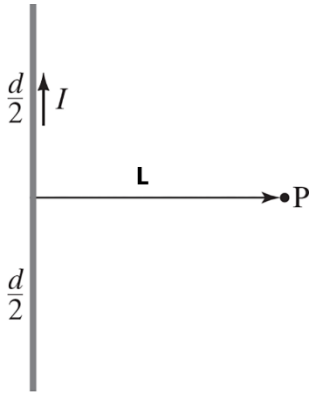
Examiners: Dr. A. Bombelli, Dr. M. Gerritsma and Dr. J. Loicq

- This exam consists of 4 open questions and 20 multiple-choice questions.
- For the multiple choice questions, mark the correct answer on the answer sheet with a black or blue pen.
- Only the calculator provided by the faculty is allowed. The use of extra material during this exam (books, notes, formula sheets, electronic storage, etc.) is FORBIDDEN.
- Put your full name and student number on your work. Do not leave the exam without handing in both answer sheets.
- A list of constants, tables and difficult equations is available at the end of this exam.

The first 4 questions are open questions. Please use the lined paper to answer these questions. Make sure you put your name and student number on all answer sheets that you hand in.

Open Question 1

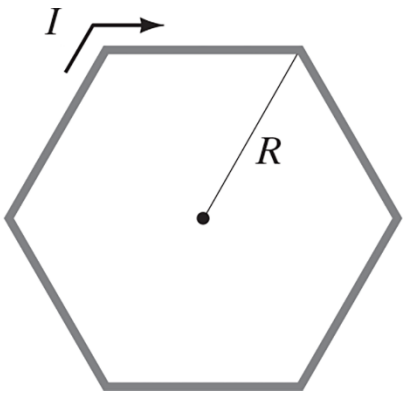
Consider a straight section of wire of length d carrying a current I, as shown below.



(A) Show that the magnitude of the magnetic field at the point P a distance L from the midpoint of the wire is $|\vec{B}| = \frac{\mu_0 I}{2\pi L} \frac{d}{(d^2+4L^2)^{\frac{1}{2}}}$ (2 points).

(B) If we take $d \to \infty$, show that the answer from point (A) is consistent with the value of $|\vec{B}|$ at a distance L from an infinitely long wire (0.5 points)

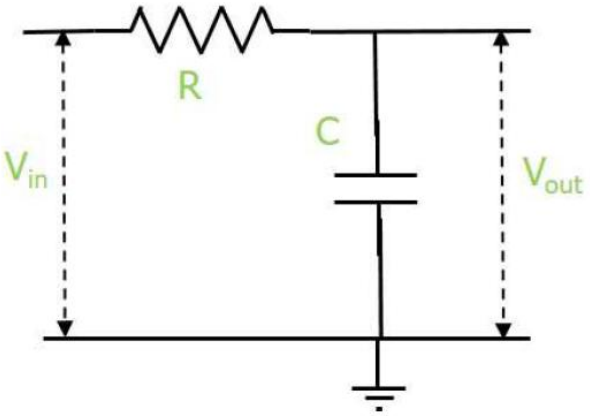
(C) We now consider the case of a wire bent into the shape of a regular polygon with n sides (in the figure below, we show the example of an hexagon where $n = 6$) and whose vertices are at a distance R from the center of the circumscribed circle. In the polygon, a current I is flowing. Using the insights from point (A), compute the expression of $|\vec{B}|$ in the center of the circle as a function of R, I, and n (2 points) (*Hint: compute the contribution of each side by dividing the polygon into n triangles, where L and d from point 1) can be expressed as a function of R and n. Then, you can sum all contributions.*)



(D) Show that, if $n \to \infty$, the answer to point (C) is consistent with the expression of $|\vec{B}|$ at the center of a circular wire of radius R where a current I is circulating, i.e., $|\vec{B}| = \frac{\mu_0 I}{2R}$ (0.5 points)

Open Question 2

A low-pass filter is shown below.



We have one resistor with $R = 1000\ \Omega$ available and, for our purposes, we need a cut-off frequency (such that $\frac{V_{out}}{V_{in}} = \frac{\sqrt{2}}{2}$) $f_{co} = 200Hz$.
(A) Compute the value of capacitance of the capacitor such that the desired cut-off frequency is obtained (1 point).
(B) After purchasing such capacitor, we realize we received two identical capacitors instead of a single one. We also realize we want to increase the bandwidth of our low-pass filter, as we are currently blocking some (higher) frequencies we should not block. How shall we connect the second capacitor to the first one (series vs parallel) and why? Motivate your answer (1 point).
(C) Given the answer to point (B), compute the new cut-off frequency f_{co} (1 point).
(D) Going back to the case with a single capacitor, let us assume we reversed the position of the resistor and the capacitor, hence creating a high-pass filter. What would be the cut-off frequency f_{co} in this case? (1 point).
(E) For a low-pass filter, show that for sufficiently high frequencies the decrease in magnitude of $\frac{V_{out}}{V_{in}}$ (in dB) is -20 dB/decade, i.e., the magnitude decreases of 20 dB if the angular frequency increases by a factor of 10 (1 point).

Open Question 3

Derive the Lensmaker's equation (5 points).

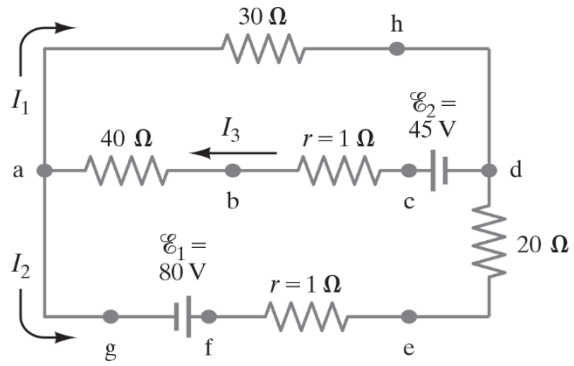
Open Question 4

Show that the law of refraction between two media (Snell's Law) can be obtained using Huygens' principle (5 points).

The next 20 questions are multiple choice question. Please use the multiple choice answer sheets to give your answer. A correct solution gives 1 point per question.

Question 1

Consider the circuit show in the figure below. All resistances and emfs are shown in the figure.



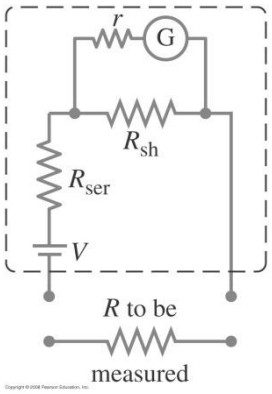
What is the magnitude value of I_3 in the direction indicated in the figure?

(A) 1.7 A
(B) 2.6 A
(C) -1.7 A
(D) 0.87 A

Question 2

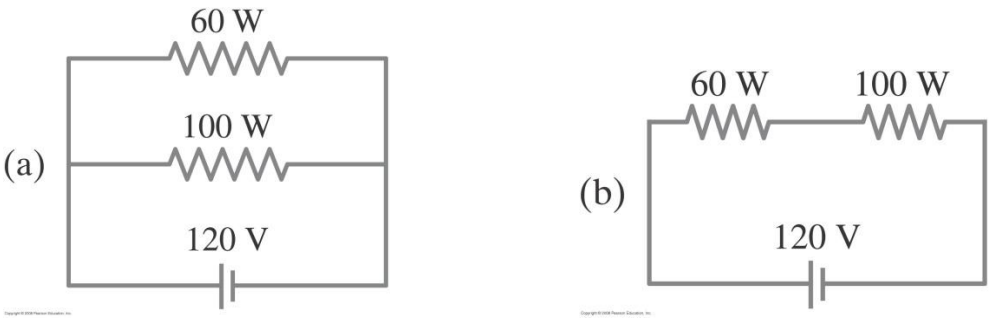
Consider the ohmmeter shown in the figure below. The resistances are r = 30 Ω, R_{sh} = 75 Ω and R_{ser} = 40 kΩ. The internal battery has a voltage of 10 V. If the galvanometer has a full-scale sensitivity of 50 μA, what is the maximum resistance this ohmmeter can measure?

(A) 1.0×10^2 kΩ
(B) 1.4×10^2 kΩ
(C) 1.6×10^2 kΩ
(D) 2.0×10^2 kΩ



Question 3

A 100W, 120V lightbulb and a 60W, 120V lightbulb are connected in two different ways as shown in the figure. In each case, which lightbulb glows more brightly? Ignore change of filament resistance with current (and temperature).

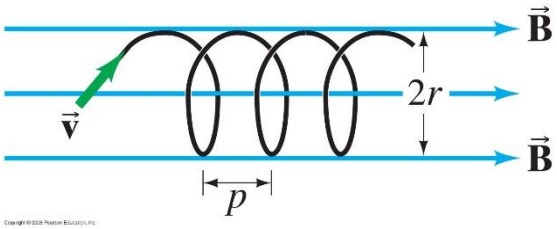


(A) The 100W bulb in series and the 100W bulb in parallel
(B) The 100W bulb in series and the 60W bulb in parallel
(C) The 60W bulb in series and the 100W bulb in parallel
(D) The 60W bulb in series and the 60W bulb in parallel

Question 4

An electron enters a uniform magnetic field $B = 0.28\text{T}$ at a 45^{o} angle. What is the pitch *p*, i.e., the distance between successive loops, see figure, of the helical path of the electron assuming its speed is 3.0×10^6 m/s?

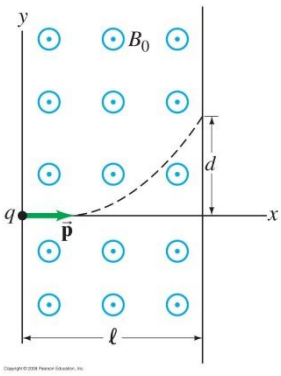
(A) $2.7 \times 10^{-3}\text{m}$
(B) $2.7 \times 10^{-4}\text{m}$
(C) $5.4 \times 10^{-3}\text{m}$
(D) $5.4 \times 10^{-4}\text{m}$



Question 5

A particle with charge q and momentum p, initially moving horizontally, enters a region with a uniform magnetic field $\vec{B} = B_0\hat{k}$, that extends over a width l as shown in the figure. The particle is deflected a distance d in the vertical direction as it leaves the region with the magnetic field. What is the magnitude of the momentum p?

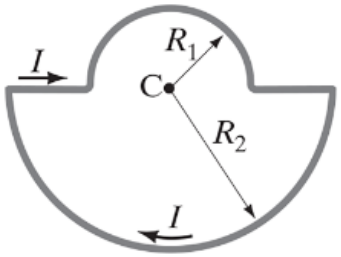
(A) $qB_0\,(d^2 + l^2)/d$
(B) $qB_0\,l^2/(2d)$
(C) $2qB_0\,(d^2 + l^2)/d$
(D) $qB_0\,(d^2 + l^2)/(2d)$



Question 6

A wire is formed into the shape of two half circles connected by equal length straight sections as shown in the figure. A current *I* flows in the circuit clockwise as shown. What is the magnitude of the magnetic field at the center point *C*?

(A) $\frac{\mu_0 I}{4}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$
(B) $\frac{\mu_0 I}{4}\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$
(C) $\frac{\mu_0 I}{2}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$
(D) $\frac{\mu_0 I}{4}\left(\frac{1}{R_1^2}+\frac{1}{R_2^2}\right)$



Question 7

Along a certain closed curve *C* in space the line integral

$$\oint \vec{B} \cdot d\vec{l} = 0$$

Which of the following conclusions is correct?

(A) The magnetic flux through the surface bounded by the curve C is zero;
(B) The current flowing along the curve is zero;
(C) The amount of current flowing through the surface bounded by C in one direction equals the amount of current flowing in the opposite direction through the surface bounded by C;
(D) The magnetic field is zero along the curve.

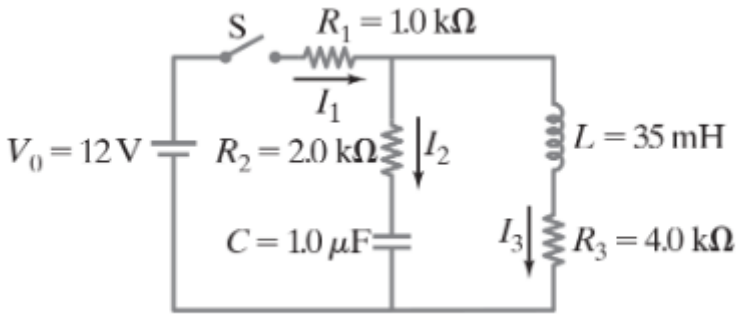
Question 8

An unknown power from a generator that operates at 51.0 kV (rms), arrives at a town at 45.0 kV (rms). The transmission lines between the generator and the town have a resistance of $R = 5.0\ \Omega$. What is the power of the generator?

(A) 58.2 MW
(B) 59.2 MW
(C) 60.2 MW
(D) 61.2 MW

Question 9

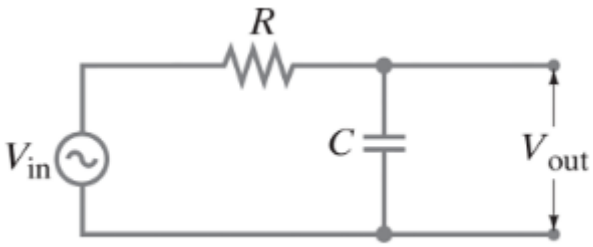
At time $t = 0$ the switch in the circuit shown in the figure is closed. After a sufficiently long time, what will be the current, I_3, through the resistor R_3?



(A) 2.4 mA
(B) 4.0 mA
(C) 5.1 mA
(D) 12 mA

Question 10

Consider the *RC* circuit as shown in the figure. In the circuit $R = 850\ \Omega$ and $C = 1.0 \times 10^{-6}$ F. For which frequency is the gain $|V_{out}/V_{in}| = 0.90$?



(A) 91 Hz
(B) 0.57 kHz
(C) 1.2 kHz
(D) 3.1 kHz

Question 11

A generator rotates at $85Hz$ in a magnetic field of $0.030T$. It has 1200 turns and produces an rms voltage of $150V$ and a rms current of $65.0A$. What is the area of each turn of the coil?

(A) $7.8 \times 10^{-3}\text{m}^2$
(B) $1.1 \times 10^{-2}\text{m}^2$
(C) $4.9 \times 10^{-2}\text{m}^2$
(D) $6.9 \times 10^{-2}\text{m}^2$

Question 12

The electric field of an electromagnetic wave pulse traveling along the *x*-axis in free space is given by

$$E_x = 0, E_y = E_0 exp[-a^2x^2 - b^2t^2 + 2abxt], E_z = 0$$

where E_0, a and b are constants. What is the speed of light expressed in terms of a and b?

(A) $\frac{1}{\sqrt{ab}}$
(B) $\sqrt{ab}$
(C) $\frac{a}{b}$
(D) $\frac{b}{a}$

Question 13

In a large circular region, there is a uniform magnetic field pointing into the page. An *x*,*y* coordinate system has its origin at the circular region's centre. A free positive point charge Q = 2.0 μC is initially at rest at a position x = + 10 cm on the *x*-axis. If the magnitude of the magnetic field is now decreased at a rate of 0.15 T/s, what is the magnitude of the force that will act on Q?

(A) 15 nN
(B) 45 nN
(C) 30 nN
(D) 60 nN

Question 14

If n_1 is the index of refraction for the incident medium and n_2 is the index of refraction for the refracting medium. In which case does a critical angle exists?

(A) in all cases, it will just have a different value
(B) when $n_1 < n_2$
(C) when $n_1 = n_2$
(D) when $n_1 > n_2$

Question 15

Which of the following characteristics describes the image formed by a plane mirror?

(A) real and inverted
(B) real and upright
(C) virtual and upright
(D) virtual and inverted

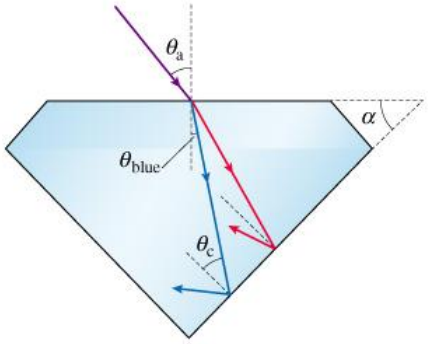
Question 16

A convex lens has a focal length *f*. An object is placed at a distance between *f* and *2f* from the lens on the axis. What is the location of the image formed by this object?

(A) between *f* and *2f*
(B) at a distance larger than *2f* from the lens
(C) at *2f*
(D) between the lens and *f*

Description Questions 17 and 18

A beam of white light is incident on the surface of a diamond at an angle θ_a, see figure. Since the index of refraction depends on the light's wavelength, the different colors that comprise white light will spread out as they pass through the diamond. For example, the indices of refraction in diamond are $n_{red} = 2.41$ for red light and $n_{blue} = 2.45$ for blue light. Thus blue light and red light are refracted at different angles inside the diamond as shown by the rays in the figure. The surrounding air has $n_{air} = 1$. Note that the angles in the figure are not to scale.



Question 17

Now consider θ_c, the angle at which the blue light refracted ray hits the bottom surface of the diamond. If θ_c is larger than the critical angle θ_{crit}, the light will not be refracted into the air, but instead, it will be totally reflected back into the diamond. What is θ_{crit} for the blue light?

(A) $\theta_{crit} = 24.09^o$
(B) $\theta_{crit} = 24.51^o$
(C) $\theta_{crit} = 25.01^o$
(D) $\theta_{crit} = 23.51^o$

Question 18

A diamond is cut such that the angle between its top surface and it bottom surface is $\alpha = 45^o$. What is the minimum value of the incident angle θ_a such that the blue light is totally, internally reflected at the bottom surface?

(A) $\theta_a = 59.71^o$
(B) $\theta_a = 59.97^o$
(C) $\theta_a = 60.97^o$
(D) $\theta_a = 61.71^o$

Question 19

A parallel beam of light from a He-Ne laser, with a wave length of 633 nm, falls on two narrow slits 0.052 mm apart. How far apart are the fringes in the center of the pattern on the screen placed 2.9 m from the two slits?

(A) $\Delta x = 3.5 \times 10^{-2}$ µm
(B) $\Delta x = 3.5 \times 10^{-2}$ mm
(C) $\Delta x = 3.5 \times 10^{-6}$ m
(D) $\Delta x = 3.5 \times 10^{-2}$ m

Question 20

Unpolarized light passes through six successive Polaroid sheets each of whose axes make a 44^o angle with the previous one. If I_0 is the intensity of the unpolarized light, what is the intensity, I, of the transmitted beam?

$(A) I = 0.016 I_0$
(B) $I = 0.16 I_0$
(C) $I = 0.019 I_0$
(D) $I = 0.19 I_0$

Fundamental constants

Quantity	Symbol	Value
Permittivity of free space	ε_0	8.85 x 10^{-12} $C^2/N.m^2$
Permeability of free space	μ_0	4π x 10^{-7} T.m/A
Speed of light in vacuum	c	3.00x10^8 m/s
Charge on electron	e	1.60x10^{-19} C
Electron rest mass	m_e	9.11x10^{-31} kg