Exam	**AESB1420**
	Mechanics 2, Electricity & Magnetism
Total number of pages	**10 pages**
Date and time	**7-3-2017** from 9:00 till 12:00 AM
Responsible lecturer	**Herman Russchenberg, Deyan Draganov, Bert Geerken**

Only the work / answers written on examination paper will be assessed, unless otherwise specified under 'Additional Information'.

Exam questions

Total number of questions: **27 questions (of which 14 open questions, 13 multiple-choice questions)**

Max. number of points to be granted: **20 points**

☐ **all questions have equal weight**
X **questions differ in weight** *(the weight is given in the sheets with questions)*

Use of tools and sources of information

- It is not allowed to use calculators. It is not allowed to use any electronic devices other than simple electronic watches and medical devices.
- It is not allowed to write exams with pencils.
- Not admitted during exams: tools and/or sources of information other than the two formula sheets provided by the examiners (one for Mechanics 2 and one for Electricity & Magnetism).

Tools and sources of information that are admitted:

☐ **books** ☐ **notes** ☐ **dictionaries** ☐ **syllabus** ☐ **calculators**

X **formula sheets (see also above)**

Additional information

The exam consists of two parts: **Mechanics 2 (M2)** and **Electricity & Magnetism (EM)**.

The exam lasts 3 hours, total points M2+EM is 20. Use exam sheets 1 to 7. The final mark will be calculated using (2/5)M2 + (3/5)EM.
Give the answers for M2 and EM on separate sheets. Give the answers to the multiple-choice questions on a separate sheet.
When handing over your sheets with answers, write on each sheet your name and study number, write on the first page the total number of sheets you submit.

Last date exam is checked: 21-7-2017 (the marking period is 15 working days at most)

! Every suspicion of fraud is mentioned to the Board of Examiners.

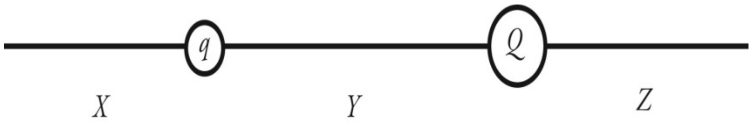
GSM OFF.

Electricity and magnetism, 3-7-2017

The exam consists of two parts. The first part is multiple-choice. You only have to give the answer. Every correct answer is worth 0.25 points, up to a total of 2 points. The second part consists of open questions. For these you have to motivate your answers. Answers without motivation are considered as wrong. The total number of points for the open questions is 8; 0.5 per sub-question.

Multiple choice, 8 questions, 0.25 point per question

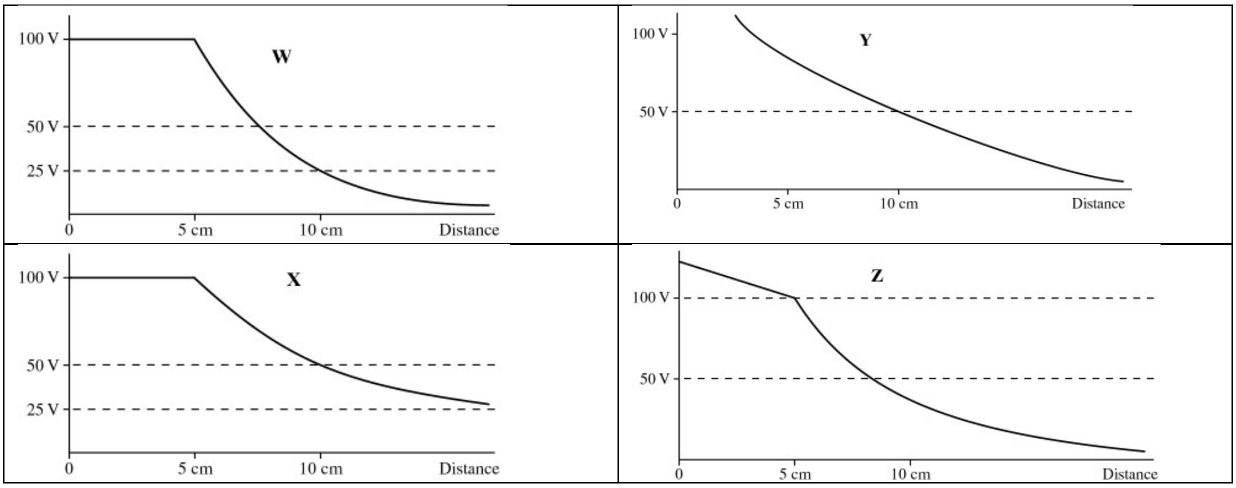
1) The figure shows two unequal point charges, q and Q, of opposite sign. Charge Q has greater magnitude than charge q. In which of the regions X, Y, Z will there be a point at which the net electric field due to these two charges is zero?



A) only regions X and Z
B) only region X
C) only region Y
D) only region Z
E) all three regions

2) Consider a spherical Gaussian surface of radius R centered at the origin. A charge Q is placed inside the sphere. To maximize the magnitude of the flux of the electric field through the Gaussian surface, the charge should be located
A) at $x = 0$, $y = 0$, $z = R/2$.
B) at the origin.
C) at $x = R/2$, $y = 0$, $z = 0$.
D) at $x = 0$, $y = R/2$, $z = 0$.
E) The charge can be located anywhere, since flux does not depend on the position of the charge as long as it is inside the sphere.

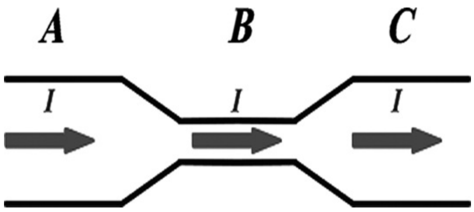
3) A metallic sphere of radius 5 cm is charged such that the potential of its surface is 100 V (relative to infinity). Which of the following plots correctly shows the potential as a function of distance from the center of the sphere?



A) plot W
B) plot X
C) plot Y
D) plot Z

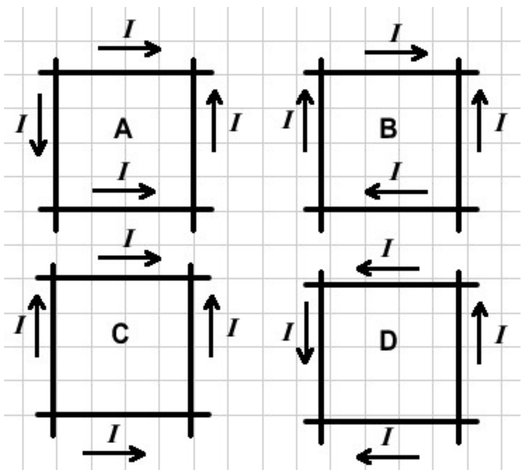
4) The charge on the square plates of a parallel-plate capacitor is *Q*. The potential across the plates is maintained with constant voltage by a battery as they are pulled apart to twice their original separation, which is small compared to the dimensions of the plates. The amount of charge on the plates is now equal to
A) 4*Q*.
B) 2*Q*.
C) *Q*.
D) *Q*/2.
E) *Q*/4.

5) The figure shows a steady electric current passing through a wire with a narrow region. What happens to the drift velocity of the moving charges as they go from region *A* to region *B* and then to region *C*?



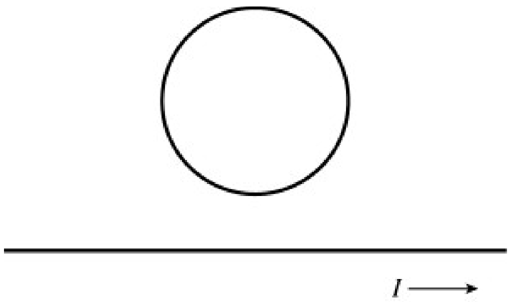
A) The drift velocity decreases from A to B and increases from B to C.
B) The drift velocity increases all the time.
C) The drift velocity remains constant.
D) The drift velocity decreases all the time.
E) The drift velocity increases from A to B and decreases from B to C.

6) The figure shows four different sets of insulated wires that cross each other at right angles without actually making electrical contact. The magnitude of the current is the same in all the wires, and the directions of current flow are as indicated. For which (if any) configuration will the magnetic field at the center of the square formed by the wires be equal to zero?



A) A
B) B
C) C
D) D
E) The field is not equal to zero in any of these cases.

7) A circular metal ring is situated above a long straight wire, as shown in the figure. The straight wire has a current flowing to the right, and the current is increasing in time at a constant rate. Which statement is true?

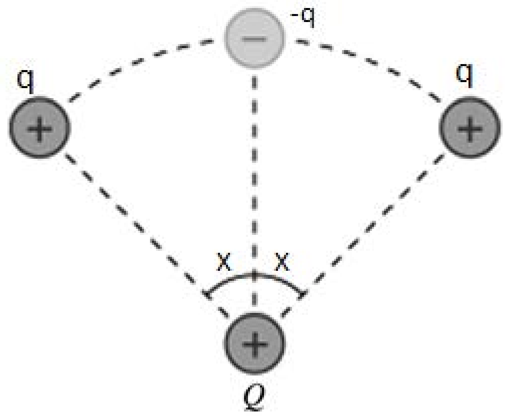


A) There is an induced current in the metal ring, flowing in a clockwise direction.
B) There is an induced current in the metal ring, flowing in a counter-clockwise direction.
C) There is no induced current in the metal ring because the current in the wire is changing at a constant rate.

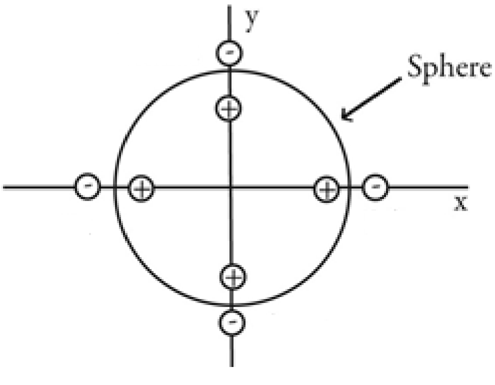
8) In an electromagnetic wave, the electric and magnetic fields are oriented such that they are
A) parallel to one another and perpendicular to the direction of wave propagation.
B) parallel to one another and parallel to the direction of wave propagation.
C) perpendicular to one another and perpendicular to the direction of wave propagation.
D) perpendicular to one another and parallel to the direction of wave propagation.

<u>Open questions, 9 assignments</u>

9) A point charge Q is located at the bottom of the figure, and the curve is a circular arc. At which angle X is there no net force on the charge *Q* due to the other point charges shown?



10) Four dipoles, each consisting of a +q charge and a -q charge separated by a distance *d*, are located in the *xy*-plane with their centers at a distance R from the origin, as shown. A sphere with radius R passes through the dipoles, as shown in the figure.



a) What is the electric flux through the sphere due to these dipoles?
b) What is the electric field strength at a distance R from the origin?
c) What is the electrical force on a charge Q at a distance 2R from the origin?
d) What is the potential at the origin? Use the dipole moment in your answer.

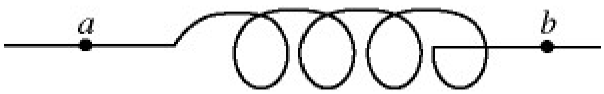
11) An electron is released from rest at a distance L from a proton. If the proton is held in place, how fast will the electron be moving when it is L/2 from the proton?

12) An air-filled capacitor is formed from two long conducting cylindrical shells that are coaxial and have radii of R and $2R$. The electric potential of the inner conductor with respect to the outer conductor is $-V_{cyl}$. The length of the capacitor is L.
a) What is the charge density on the inner shell?
b) How much energy is stored in the capacitor?
c) What is the capacity?
d) If we double the radius of the outer shell and keep the potential difference constant, how much becomes the energy stored in the capacitor then?

13) A cylindrical wire of diameter d carries a current I. The potential difference between points on the wire that are at a distance L apart is V_L.
(a) What is the electric field in the wire?
(b) What is the resistivity of the material of which the wire is made?

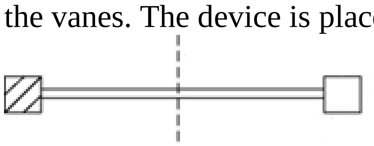
14) A wire carrying a current is shaped in the form of a circular loop of radius R. If the magnetic field strength that this current produces at the center of the loop is B, what is the magnitude of the current that flows through the wire?

15) In the figure, the current in a solenoid having no appreciable resistance is flowing from b to a and is decreasing at a rate of I_0 A/s. The self-induced emf in the solenoid is found to be V_0. The self-inductance is defined as the ratio of magnetic flux and current.



(a) What is the self-inductance of the solenoid?
(b) In which does the induced current flow?

16) A radiometer has two square vanes, attached to a light horizontal cross arm, and pivoted about a vertical axis through the center, as shown in the figure. One vane is silvered and it reflects all radiant energy incident upon it. The other vane is blackened and it absorbs all incident radiant energy. Electromagnetic waves, coming from all directions, are incident upon the vanes. The device is placed in vacuum. Describe what will happen.



MECHANICS 2, 3-7-2017

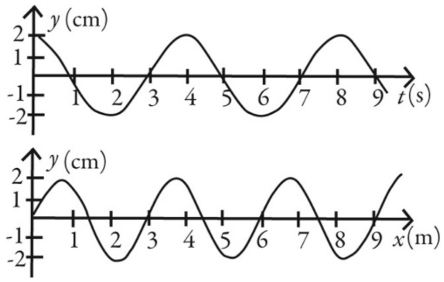
The exam consists of two parts. ***The first part is multiple-choice questions. For this part, you only have to give the answer****. Each correct answer is worth 0.4 points, up to a total of 2 points.* ***The second part consists of open questions. For these questions, you have to motivate your answers, i.e., show all the steps that lead to the answer you provide****. Answers without motivation are considered wrong and bring no points. Answers that show only part of the required steps to reach the correct answer will result in receiving a proportional part of points from the total amount of points given for this answer. (For example, if a subquestion brings 1 point, but you only show half of the path to the correct answer, you will get 0.5 points.) An open question might have alternative paths of reaching the correct answer – all such paths are considered correct. The total number of points for the open questions is 8. If an open question consists of subquestions, translation of the result of a wrong calculation from one subquestion to another subquestion is not judged as an error.*

<u>Multiple choice, 5 assignments, 0.4 points per question</u>

1) If we double only the spring constant of a vibrating ideal mass-and-spring system, the mechanical energy of the system
A) increases by a factor of $\sqrt{2}$.
B) decreases by a factor of $\sqrt{2}$.
C) increases by a factor of 2.
D) decreases by a factor of 2.
E) increases by a factor of 4.
F) decreases by a factor of 4.

2) A frictionless simple pendulum with length L and mass m swings with period T. If both L and m are doubled, what is the new period?
A) $\sqrt{2}T$
B) $2T$
C) $4T$
D) $T/\sqrt{2}$
E) $T/2$
F) $T/4$

3) The figure shows the displacement y of a wave at a given position as a function of time and the displacement of the same wave at a given time as a function of position. What is the frequency of the wave.



A) 4.0 Hz
B) 3.0 Hz
C) 0.25 Hz
D) 0.33 Hz

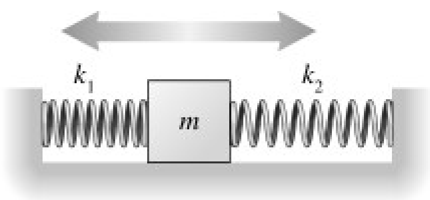
4) A guitar string is fixed at both ends. When you pull the string, you induce a standing wave in a specific mode characterized by a certain frequency and wavelength. You tighten the string to increase its tension and then pull the string again to induce a standing wave in the same mode as before. What can you say about the frequency and the wavelength now?
A) The wavelength increased, but the frequency of the vibrational mode decreased.
B) The wavelength increased, while the frequency of the vibrational mode was not affected.
C) And the wavelength and the frequency of the vibrational mode increased.
D) The frequency of the vibrational mode increased, but the wavelength decreased.
E) The frequency of the vibrational mode increased, while the wavelength was not affected.
F) Neither the frequency of the vibrational mode nor the wavelength were affected.

5) To derive the acoustic wave equation in three dimensions, we used a system of coupled equations. One of the equations is $-\nabla p = \rho_0 \frac{\partial \vec{v}}{\partial t}$. This equation describes what process when the wave passes?
A) Curl.
B) Compression/expansion.
C) Rotation.
D) Translation.

<u>Open questions, 6 assignments</u>

6) The position of an object that is oscillating on an ideal spring following a simple harmonic motion is given by the equation $x(t)$ = (30 cm) $cos[(\pi/3\ s^{-1})t]$. At time t = 0.5 s,
(a) how fast is the object moving (in metres per second)? ***(0.7 points)***
(b) what is the magnitude (absolute value) of the acceleration of the object (in metres per second squared)? ***(0.4 points)***
Give the answers till the second digit after the decimal point.

7) A 3.0-kg block on table is connected to two ideal massless springs of the same length, which are neither stretched nor compressed. The springs' opposite ends are fixed to two opposite walls, as shown in the figure. The block does not experience friction neither with the air nor with the table. The block is displaced and let to oscillate following simple harmonic motion. What is the angular frequency of the oscillation (in one over second) if the spring constants are $k1$ = 7.0 N/m and $k2$ = 5.0 N/m? ***(1.1 point)***



Give the answer till the second digit after the decimal point.

8) You are investigating a physical pendulum while swinging back and forth. You are taking measurements of its potential energy and notice that the potential energy is linearly proportional to the square of angular displacement, with a proportionality factor of 40. You know the inertia of the pendulum, it is 5 kg.m^2. The measurements are being made under vacuum, so there is no friction with the air. When the pendulum is going to be used in the open air, it is going to experience damped motion. You know that you can counter this by applying a driving force with a certain frequency. But to be sure that you do not enter into resonance, you want to stay away from the resonance frequency. What is the resonance frequency of the physical pendulum (in one over second)? ***(1.8 points)***
Give the answer rounded to the closest integer number.

9) A standing wave of frequency 40 Hz is produced on a string that has mass per unit length 0.02 kg/m. With what tension must the string be stretched between two walls if adjacent nodes in the standing wave are to be 0.5 m apart? ***(1 point)***
Give the answer as an integer.

10) You are experimenting with what you have learned from Mechanics 2. You are standing between two friends that are some distance apart, and form one line. Each of them makes so that the same sound wave with a frequency of 170 Hz is emitted. You start running towards one of them along the line and perceive a beat every 2 s (i.e., 2 $\frac{1}{s}$). How fast are you running? (The speed of sound in the air can be taken to be 340 m/s.) ***(1.2 points)***
Give the answer as an integer.

11) You are watching supersonic experiment with a ground vehicle (may be in the near future) that takes place on a special track. You are 680 m perpendicularly away from the finish point on the track. When the ground vehicle is at the finish point, a sound is emitted to mark the reached finish. The wavefront of the shock wave from the vehicle's turbine reaches you 0.5 s after you hear the sound emitted at the finish point. If the speed of sound in the air is 340 m/s, what was the speed of the ground vehicle at the finish? ***(1.8 points)***
Give the answer as an integer.

Equation Sheet

MECHANICS 2

27-06-2016

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$x(t) = A\cos(\omega t)$$

$$\omega = \sqrt{\frac{\mathrm{k}}{\mathrm{m}}}$$

$$A(\omega_d) = \frac{F_0}{m\sqrt{\left(\omega_d^2 - \omega_0^2\right)^2 + \frac{b^2\omega_d^2}{m^2}}}$$

$$v = \lambda f$$

$$y(x,t) = A\cos(kx - \omega t)$$

$$k = \frac{2\pi}{\lambda}$$

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

$$\lambda' = \lambda\left(1 \pm \frac{u}{v}\right)$$

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

$\vec{F}_{12} = \frac{kq_1q_2}{r^2}\hat{r}$ (Coulomb's law)

$\vec{E} = \int d\vec{E} = \int \frac{k\,dq}{r^2}\hat{r}$ (field of a continuous charge distribution)

$E = \frac{\sigma}{\epsilon_0}$ (field at conductor surface)

$E = \frac{2k\lambda}{r}$ (field of electrical line)

$\Delta V_{AB} = \frac{\Delta U_{AB}}{q} = -\int_A^B \vec{E} \cdot d\vec{r}$ (electric potential difference)

$V_{\infty r} = V(r) = \frac{kq}{r}$ (point-charge potential)

$V = \int dV = \int \frac{k\,dq}{r}$ (potential of a continuous charge distribution)

$C = \frac{Q}{V}$ (capacitance)

$U = \frac{1}{2}CV^2$ (energy in a capacitor)

$u_E = \frac{1}{2}\epsilon_0 E^2$ (electric energy density)

$u_B = \frac{B^2}{2\mu_0}$ (magnetic-energy density)

$I = \frac{dQ}{dt}$ (instantaneous current)

$\vec{J} = \sigma\vec{E}$ (Ohm's law, microscopic version)

$I = \frac{V}{R}$ (Ohm's law, macroscopic version)

$P = IV$ (electric power)

$\vec{F}_B = q\vec{v} \times \vec{B}$ (magnetic force)

$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$ (electromagnetic force)

$\vec{F} = I\vec{l} \times \vec{B}$ (magnetic force on a current)

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \hat{r}}{r^2}$ (Biot–Savart law)

$\vec{\mu} = NI\vec{A}$ (magnetic dipole moment, N-turn current loop)

$\vec{S} = \frac{\vec{E} \times \vec{B}}{\mu_0}$ (Poynting vector)

Gauss for $\vec{E}$	$\oint \vec{E}\cdot d\vec{A} = \frac{q}{\epsilon_0}$	How charges produce electric field; field lines begin and end on charges.	(29.2)
Gauss for $\vec{B}$	$\oint \vec{B}\cdot d\vec{A} = 0$	No magnetic charge; magnetic field lines don't begin or end.	(29.3)
Faraday	$\oint \vec{E}\cdot d\vec{r} = -\frac{d\Phi_B}{dt}$	Changing magnetic flux produces electric field.	(29.4)
Ampère	$\oint \vec{B}\cdot d\vec{r} = \mu_0 I + \mu_0\epsilon_0\frac{d\Phi_E}{dt}$	Electric current and changing electric flux produce magnetic field.	(29.5)

$B = \mu_0 nI$ (solenoid field)

$R = \frac{\rho L}{A}$

$\mathcal{E} = -\frac{d\Phi_B}{dt}$ (Faraday's law)

$U = \frac{1}{2}LI^2$ (energy stored in inductor)