TU Delft

Faculty of Aerospace Engineering

Resit EXAM: Waves and Electromagnetism (AE1240-II)

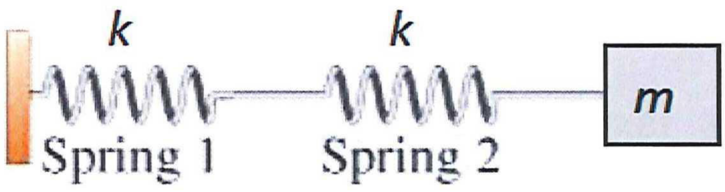
10 August 2016, 13:30 – 16:30 16 pages

Please read these instructions first:

1) This exam contains 25 four-choice questions. Please mark one answer per question on the 'Four Choice Response Form'.
2) **If you want to correct your answer, mark a new box and draw a cross through the originally marked box.** In case of more corrections per answer it is recommended to ask for a new form, since the forms are processed automatically.
3) Do not forget to write your **name** and **7-digit student number**. Also mark your student number in the corresponding box. If these are missing, the exam result is invalid! Finally sign the form.
4) Use of the book "Physics for Scientists & Engineers with modern physics", by Giancoli, copies of lectures slides or any other material (cell phones, etc.) is not allowed. Only the use of your (graphical) pocket calculator is allowed.
5) **Please do not turn over the page before 13:30.**

Question 1

Consider two massless springs connected in series. Both springs have spring constant k. A mass m, attached to this spring system according to the figure below, is in simple harmonic motion. What is de radial frequency?



(A) $\omega = 2\sqrt{\dfrac{k}{m}}$

(B) $\omega = \sqrt{\dfrac{2k}{m}}$

(C) $\omega = \sqrt{\dfrac{k}{m}}$

(D) $\omega = \sqrt{\dfrac{k}{2m}}$

Question 2

A 4.20 g bullet embeds itself in a 20.0 kg block, which is attached to a horizontal spring with a spring constant of 980 N/m. The maximum compression of the spring is 2.70 cm. What is the speed of the bullet just before it hits the block?

(A) 700 m/s
(B) 800 m/s
(C) 900 m/s
(D) 1000 m/s

Question 3

A 2.00 kg mass oscillates on the end of a spring with spring constant 12.0 N/m. Its amplitude of oscillation decreases from 10.0 cm to 1.0 cm in 4.00 minutes. What is the linear damping coefficient b of this oscillator?

(A) 0.0384 Nsm^{-1}
(B) 0.311 Nsm^{-1}
(C) 0.622 Nsm^{-1}
(D) 1.76 Nsm^{-1}

Question 4

Four waves are described by the following expressions, where distance x is measured in meters and time t in seconds:

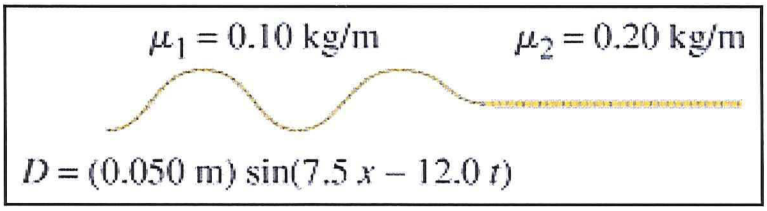
I. $y(x,t) = 0.12\cos(3x - 21t)$
II. $y(x,t) = 0.15\cos(6x + 42t)$
III. $y(x,t) = 0.13\cos(6x + 21t)$
IV. $y(x,t) = -0.23\cos(3x - 42t)$

Which of these waves travels with the highest speed?

(A) I (B) II
(C) III (D) IV

Question 5

A cord has two sections with linear densities of 0.1 kg/m and 0.2 kg/m, see figure below. An incident wave, given by $D = (0.050\text{ m})\sin(7.5x - 12.0t)$, where x is in meters and t in seconds, travels along the lighter cord.



What is the wavelength when the wave travels on the heavier section?

(A) 0.42 m (B) 0.59 m
(C) 0.84 m (D) 1.2 m

Question 6

Which of the following traveling waves is a solution to the wave equation

$$\frac{\partial^2 z(x,t)}{\partial x^2} = C\frac{\partial^2 z(x,t)}{\partial t^2} \qquad \text{with } C \text{ a constant.}$$

(A) $z(x,t) = A\cos\left[k(x - \frac{t}{C^2})\right]$ (B) $z(x,t) = A\cos\left[k(x - C^2 t)\right]$

(C) $z(x,t) = A\cos\left[k\left(x - \frac{t}{\sqrt{C}}\right)\right]$ (D) $z(x,t) = A\cos\left[k(x - \sqrt{C}\,t)\right]$

(A and k are constants, x is distance, t is time)

Question 7

A bat flies toward a wall at a speed of 3.0 m/s. As it flies, the bat emits an ultrasonic sound wave with frequency 34.0 kHz . What frequency does the bat hear in the reflected wave? Take 343 m/s for the sound speed.

(A) 32.8 kHz
(B) 34.0 kHz
(C) 34.6 kHz
(D) 35.2 kHz

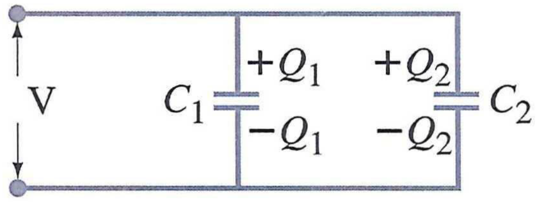
Question 8

A person standing a certain distance from an airplane with four equally noisy jet engines experiences a sound level of 125 dB . What sound level would this person experience if the captain shuts down two of the four engine?

(A) 119 dB
(B) 122 dB
(C) 124 dB
(D) 128 dB

Question 9

Two capacitors are connected in parallel to a battery with voltage V as shown in the figure. The capacitance of C_2 is five times higher than the capacitance of C_1. When the capacitors are fully charged the battery is disconnected. Then a dielectric with dielectric constant $K = 3$ is inserted in capacitor C_1. What is the voltage over capacitor C_1?



(a) Initial configuration.

(A) V (B) $\frac{3}{4}V$

(C) $\frac{3}{8}V$ (D) $\frac{5}{3}V$

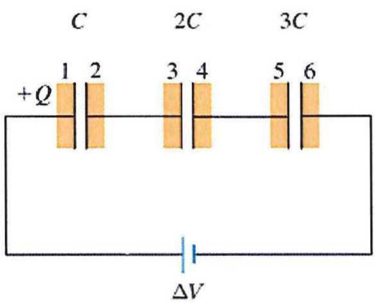
Question 10

A static charge distribution in space generates a potential field $V(x,y,z) = x^2y^3 - z$ in volts. A positive point charge q is placed at $x = y = z = 1$. What is the direction of the Coulomb force acting on the point charge?

(A) No force, therefore no direction.
(B) The force is pointing in the (2,3,-1) direction.
(C) The force is pointing in the (-2,-3,1) direction.
(D) The force is pointing in the positive z-direction.

Question 11

Three capacitors are connected to each other in series and then to a battery. The values of the capacitors are C, $2C$ and $3C$, and the applied voltage is ΔV .



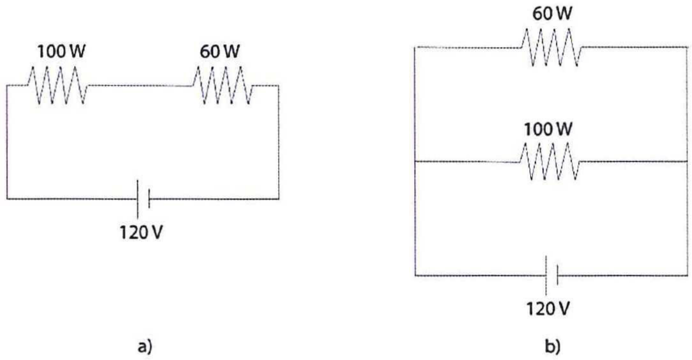
Determine the potential across the second capacitor (the one with capacitance $2C$).

(A) $\frac{2}{11}\Delta V$ (B) $\frac{3}{11}\Delta V$

(C) $\frac{6}{11}\Delta V$ (D) $\frac{1}{3}\Delta V$

Question 12

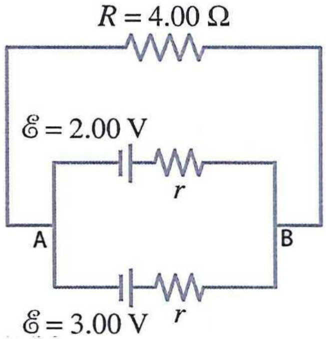
A 100 W, 120 V light bulb and a 60 W, 120 V light bulb are connected in two different ways as shown in the figure. Which light bulb glows more brightly? (Ignore change of filament resistance due to temperature changes).



(A) 60 W bulb in Fig a) and 60 W bulb in Fig b).
(B) 100 W bulb in Fig a) and 60 W bulb in Fig b).
(C) 60 W bulb in Fig a) and 100 W bulb in Fig b).
(D) 100 W bulb in Fig a) and 100 W bulb in Fig b).

Question 13

Suppose two batteries with unequal emfs of 2.00 V and 3.00 V are connected as shown in the figure. If each internal resistance is $r = 0.500\ \Omega$ and $R = 4.00\ \Omega$, what is the voltage delivered by the battery package between the points A and B?



(A) $\frac{40}{17}$V　　(B) $\frac{10}{17}$V
(C) $\frac{48}{17}$V　　(D) $\frac{88}{17}$V

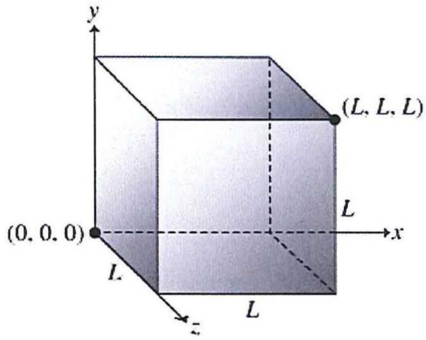
Question 14

A copper wire of 3.2 mm in diameter carries a 0.5 A current. The resistivity of copper is $1.68\times10^{-8}\,\Omega\cdot\mathrm{m}$. What is the electric field E inside the wire?

(A) 1.0×10^{-3} V/m　　(B) 1.0×10^{-2} V/m
(C) 1.0×10^{-1} V/m　　(D) 1.0 V/m

Question 15

A cube has one corner at the origin and the opposite corner at the point *(L,L,L)*. The sides of the cube are parallel to the coordinate planes. The electric field in and around the cube is given by $\vec{E} = (x - L)\hat{i} + z\hat{k}$. What is the net charge inside the cube?



(A) $\varepsilon_0 L^3$

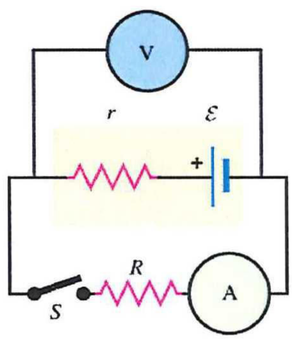
(B) $-2\varepsilon_0 L^3$

(C) 0

(D) $2\varepsilon_0 L^3$

Question 16

When switch S in the figure is open, the voltmeter V of the battery reads 3.08 V. When the switch is closed, the voltmeter reading drops to 2.93 V, and the ammeter A reads 1.62 A. Assume that the two meters are ideal, so they do not affect the circuit. Determine the internal resistance *r*.



(A) 46.3 mΩ

(B) 92.6 mΩ

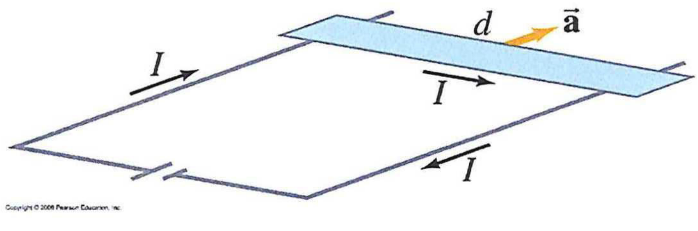
(C) 1.81 Ω

(D) 1.90 Ω

Question 17

A projectile launcher is shown in the figure below. A large current moves in a closed loop composed of fixed rails, a power supply, and a very light, frictionless bar toughing the rails. A 1.9 T magnetic field is perpendicular to the plane of the circuit. If the rails are a distant d = 25 cm apart, and the bar has a mass of 1.4 g, what constant current flow is needed to accelerate the bar from rest to 25 m/s in a distance of 1.0 m.

(A) 0.86 A
(B) 0.88 A
(C) 0.90 A
(D) 0.92 A



Question 18

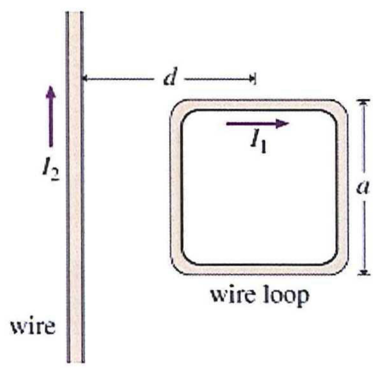
A square loop of wire with side length a carries a current I_1. The center of the loop is located a distance d from an infinite wire carrying a current I_2. The infinite wire and loop are in the same plane; two sides of the square loop are parallel to the wire and two are perpendicular as shown in the figure. What is the magnitude of the net force on the loop?

(A) $\dfrac{\mu_0 I_1 I_2 a^2}{2\pi\left(d^2-\dfrac{a^2}{4}\right)}$

(B) $\dfrac{\mu_0 I_1 I_2 ad}{2\pi\left(d^2-\dfrac{a^2}{4}\right)}$

(C) $\dfrac{\mu_0 I_1 I_2 d^2}{2\pi\left(d^2-\dfrac{a^2}{4}\right)}$

(D) $\dfrac{\mu_0 I_1 I_2 ad}{\pi\left(d^2-\dfrac{a^2}{4}\right)}$



Question 19

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 $Q = 2.0\ \mu C$ 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) 30 nN
(C) 45 nN
(D) 60 nN

Question 20

We consider the magnetic field due to a set of two wires with antiparallel currents as shown in the diagram. Each of the wires carries a current of magnitude I. The current in wire 1 is directed out of the page and that in wire 2 is directed into the page. The distance between the wires is $2d$. The x-axis is perpendicular to the line connecting the wires and is equidistant from the wires.

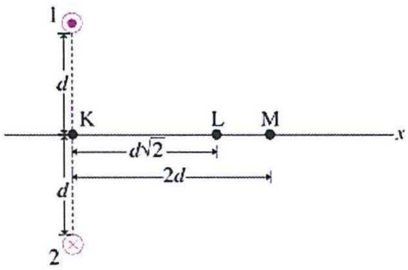
Point L is located a distance $d\sqrt{2}$ from the midpoint between the two wires. Find the magnitude of the net magnetic field created at point L by both wires.

(A) $\dfrac{\mu_0 I}{\pi d}$

(B) $\dfrac{\mu_0 I\sqrt{2}}{\pi d}$

(C) $\dfrac{\mu_0 I}{\pi d\sqrt{2}}$

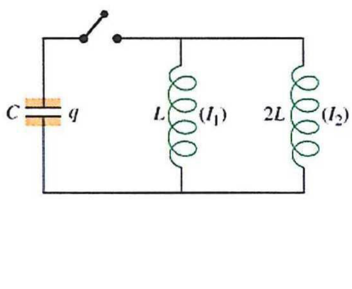
(D) $\dfrac{\mu_0 I}{3\pi d}$



Question 21

A capacitor with capacitance C is connected in parallel to two inductors: inductor 1 with inductance L, and inductor 2 with inductance $2L$, as shown in the figure. The capacitor is charged up to a voltage V. There is no current in the inductors. Then the switch is closed. What is the maximum current through inductor 2.

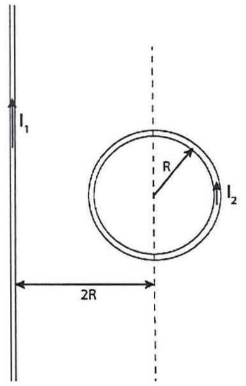
(A) $V\sqrt{\dfrac{C}{6L}}$
(B) $V\sqrt{\dfrac{2C}{3L}}$
(C) $\dfrac{2}{3}V\sqrt{\dfrac{C}{L}}$
(D) $V\sqrt{\dfrac{3C}{2L}}$



Question 22

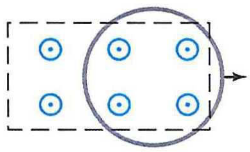
A wire carries a current I_1 and a loop in the plane carries a current I_2. The loop has a radius R and the center of the loop is placed at a distance $2R$ from the wire as shown in the figure. What is the magnitude of I_1 if the magnetic field at the center of the loop is zero?

(A) $I_1 = I_2$
(B) $I_1 = \sqrt{2}I_2$
(C) $I_1 = 2I_2$
(D) $I_1 = 2\pi I_2$

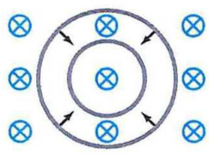


Question 23

In the figure two circular loops in a magnetic field are drawn. In which direction is the current induced in the circular loop for both situations?



(a)
Pulling a round loop to the right out of a magnetic field which points out of the page

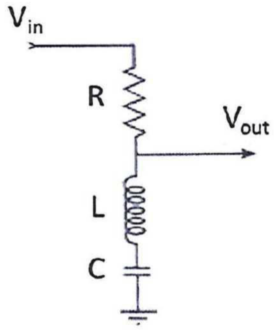


(b)
Shrinking a loop in a magnetic field pointing into the page

(A) (a) clockwise (b) clockwise
(B) (a) clockwise (b) counterclockwise
(C) (a) counterclockwise (b) clockwise
(D) (a) counterclockwise (b) counterclockwise

Question 24

The figure below shows a circuit called a notch filter, used to remove a narrow band of frequencies. Here $R = 100\ \Omega$, $C = 230$ pF and $L = 110\ \mu$H. At which frequency is the voltage gain $V_{out}/V_{in} = 0$, i.e. which frequency is totally eliminated?



(A) 0.32 MHz
(B) 1.0 MHz
(C) 3.1 MHz
(D) 6.3 MHz

Question 25

An electromagnetic wave has a magnetic field with amplitude $3.0\text{x}10^{-6}$ T. What is the intensity of the wave?

(A) $1.1\text{x}10^3$ W/m^2
(B) $1.5\text{x}10^3$ W/m^2
(C) $2.2\text{x}10^3$ W/m^2
(D) $3.0\text{x}10^3$ W/m^2

Formulas exam physics II, AE1240-II

Equation of motion 'simple harmonic oscillator'	$\frac{d^2x}{dt^2} + \frac{k}{m}x = 0$	position x, time t, spring constant k, mass m
Solution	$x = A\cos(\omega t + \phi)$	amplitude A, phase angle ϕ, angular frequency $\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T} = 2\pi f$ with frequency f and period T
Energy in the simple harmonic oscillator	$E = \frac{1}{2}kA^2 = \frac{1}{2}mv_{max}^2 = \frac{1}{2}kx^2 + \frac{1}{2}mv^2$	maximum velocity v_{max}, instantaneous velocity v
Angular frequency simple pendulum	$\omega = \sqrt{\frac{g}{l}}$	acceleration of gravity g, length of the cord l (valid only for small angles θ)
Equation of motion 'damped harmonic oscillator'	$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$	damping constant b in $F_{damping} = -bv$
Solution	$x = Ae^{-\gamma t}\cos\omega' t$	Radial frequency

		$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$ and $\gamma = \frac{b}{2m}$
Equation of motion 'forced oscillation'	$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F_0 \cos \omega t$	angular frequency ω (applied externally)
Solution	$x = A_0 \cos(\omega t + \phi_0)$ with $A_0 = \frac{F_0}{m\sqrt{(\omega^2 - \omega_0^2)^2 + \frac{b^2\omega^2}{m^2}}}$	resonance frequency $\omega_0{}^2 = \frac{k}{m}$

Wave velocity v is product of wavelength λ and frequency f	$v = \lambda f$	
Velocity of transverse waves on a stretched string/cord	$v = \sqrt{\frac{F_T}{\mu}}$	Tension in string F_T, mass per unit length of the string μ
Velocity of longitudinal waves (general)	$v = \sqrt{\frac{\text{elastic force factor}}{\text{inertia factor}}}$	
Velocity of longitudinal waves in long solid rod	$v = \sqrt{\frac{E}{\rho}}$	elastic modulus E, mass density ρ
Velocity of longitudinal waves in fluid	$v = \sqrt{\frac{B}{\rho}}$	bulk modulus B
Intensity I of a wave	$I = 2\pi^2 \rho v f^2 A^2$	I in W/m^2
Intensity I and amplitude A versus distance r from the source for spherical wave	$I \propto \frac{1}{r^2}, \quad A \propto \frac{1}{r}$	
Traveling sinusoidal wave (1D)	$D(x,t) = A \sin\left(\frac{2\pi}{\lambda}(x - vt)\right) = A\sin(kx - \omega t)$	displacement D, wavenumber $k = \frac{2\pi}{\lambda}$, radial frequency $\omega = 2\pi f$
Resonant frequencies of standing waves on a string fixed at both ends	$f_n = n\frac{v}{2l} \quad n = 1,2,3,\ldots$	length of string l valid for stringed instruments and wind instruments (open tubes)
Snell's law of refraction	$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$	angle of incidence θ_1, angle of refraction θ_2, v_1 is wave velocity of medium where incident wave is, v_2 is wave velocity where refracted wave is

Speed of sound in air	$v = (331 + 0.6\,T)$ m/s	temperature T in °C

Pressure amplitude of a sound wave with frequency f	$\Delta P_M = 2\pi\rho v A f$	displacement amplitude A
Sound level in dB	$\beta = 10\log\left(\frac{I}{I_0}\right)$	intensity of the sound I, reference intensity $I_0 = 10^{-12}$ W/m^2 (logarithm is to the base 10)
Intensity of a sound wave	$I = \frac{(\Delta P_M)^2}{2\rho v}$	
Doppler effect: (minus sign: source moving towards stationary observer, plus sign: moving away)	$f' = \frac{f}{\left(1 \mp \frac{v_{source}}{v}\right)}$	observed frequency f', source speed v_{source}, sound speed v
Doppler effect: (plus sign: observer moving towards stationary source, minus sign: moving away)	$f' = f\left(1 \pm \frac{v_{obs}}{v}\right)$	observer speed v_{obs}
Doppler effect: source and observer moving	$f' = f\left(\frac{1 \pm \frac{v_{obs}}{v}}{1 \mp \frac{v_{source}}{v}}\right)$	
Angle θ of the cone a shock wave consists of	$\sin\theta = \frac{v}{v_{source}}$	source speed v_{source} bigger than sound speed v

$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$	Coulomb's law: Magnitude of the force F (in N) between two charges Q_1 and Q_2 (both in C), with r (in m) the distance between the two charges.
$\vec{E} = \frac{\vec{F}}{q}$	The electric field vector at any point due to one or more charges is defined as the force per unit charge that would act on a positive test charge placed at that point.
$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$	Magnitude of the electric field (in N/C) at a distance r (in m) from a point charge Q (in C).
$E = \frac{\sigma}{2\varepsilon_0}$	Electric field (in N/C) above or below an 'infinite' plane of any shape holding a charge density σ (in C/m^2).
$\Phi_E = \vec{E}.\vec{A}$	Electric flux (in Nm^2/C) through a flat area A for a uniform electric field $\vec{E}$ (direction of $\vec{A}$ is chosen perpendicular to the surface whose area is A).
$\Phi_E = \int \vec{E}.d\vec{A}$	Electric flux in case the field is not uniform.
$\oint \vec{E}.d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$	Gauss's law: Net flux passing through any closed surface (left-hand side of equation) equals the net charge Q_{encl} (in C) enclosed by that surface divided by ε_0.
$V_b - V_a = -\int_a^b \vec{E}.d\vec{l}$	Potential difference (in V or J/C) between two points, a and b, given the electric field $\vec{E}$ (in N/C or V/m).

$V_b - V_a = -Ed$	Potential difference (in V or J/C) between two points, *a* and *b*, in the case the electric field is uniform (with magnitude *E*). *d* (in m) is the distance between the two points.
$V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r}$	Electric potential *V* (in V) due to a single point charge *Q* at a distance *r* (in m) from this point charge.
$E_x = -\dfrac{\partial V}{\partial x},\ E_y = -\dfrac{\partial V}{\partial y},\ E_z = -\dfrac{\partial V}{\partial z}$	Components of the electric field vector $\vec{E} = (E_x, E_y, E_z)$ given the known potential $V(x, y, z)$.
$C = \dfrac{Q}{V}$	Definition of capacitance *C* (in F): ratio of the charge *Q* (in C) to potential difference *V* (in V) between the two conductors of a capacitor (the two conductors of a capacitor hold equal and opposite charges of magnitude *Q*).
$C = \varepsilon_0 \dfrac{A}{d}$	Capacitance *C* (in F) of a parallel-plate capacitor with plate area *A* (in m^2) and separation *d* (in m).
$C_{eq} = C_1 + C_2 + \ldots$	Equivalent capacitance when capacitors are connected in parallel.
$\dfrac{1}{C_{eq}} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$	Equivalent capacitance when capacitors are connected in series.
$U = \dfrac{1}{2}QV = \dfrac{1}{2}CV^2 = \dfrac{1}{2}\dfrac{Q^2}{C}$	A charged capacitor stores an amount of energy *U* as a function of *C*, *Q*, or *V*
$u = \dfrac{1}{2}\varepsilon_0 E^2$	In any electric field $\vec{E}$ in free space the energy density *u* (energy per unit volume)
$C = K\varepsilon_0 \dfrac{A}{d} = \varepsilon \dfrac{A}{d}$	Capacitance in dielectrics. *K* is the dielectric constant.
$\varepsilon = K\varepsilon_0$	Permittivity for a dielectric material
$u = \dfrac{1}{2}K\varepsilon_0 E^2 = \dfrac{1}{2}\varepsilon E^2$	The energy density for a dielectric material
$V = IR$	Relation between resistance *R* (in Ω) of a device and the current *I* (in A) in the device and the potential difference *V* (in V) applied across it. Ohm's law: *R* is a constant independent of *V*.
$R = \dfrac{\rho l}{A}$	Resistance *R* (in Ω) of a wire with cross-sectional area *A* (in m^2), length *l* (in m) and resistivity ρ (in Ω m).
$P = IV = I^2R = \dfrac{V^2}{R}$	Power *P* (in W) transformed in a resistance *R* (in Ω) with *I* (in A) the current in the resistor and *V* (in V) the potential difference applied across it.
$I_{rms} = \dfrac{I_0}{\sqrt{2}},\quad V_{rms} = \dfrac{V_0}{\sqrt{2}}$	The rms values of sinusoidally alternating currents and voltages.
$\vec{j} = nq\vec{v}_d$	Relation between the current density $\vec{j}$ and the number of charge carriers *n* per unit volume, the charge *q* per particle and the drift velocity $\vec{v}_d$.
$\vec{j} = \sigma\vec{E}$	Relation between the current density, the electric field and the conductivity σ.
$\sigma = \dfrac{1}{\rho}$	The conductivity is one over the resistivity.

$\rho_T = \rho_0\left[1+\alpha(T-T_0)\right]$	Resistivity ρ_T at temperature T expressed in terms of the resistivity ρ_0 at temperature T_0. The coefficient α is the temperature coefficient of resistivity (in $1/C^\circ$)
$R_{eq} = R_1 + R_2 + \ldots$	Equivalent resistance when resistors are connected in series.
$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$	Equivalent resistance when resistors are connected in parallel.
$\tau = RC$	The time constant τ of an RC circuit is the resistance multiplied by the capacitance.
$\vec{F} = I\vec{l} \times \vec{B}$	Force (in N) exerted by a uniform magnetic field $\vec{B}$ (in T) on a wire of length $\vec{l}$ (in m) that carries a current I (in A).
$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$	Force on a charge q moving with velocity $\vec{v}$ in an electric field $\vec{E}$ (in N/C) and magnetic field $\vec{B}$.
$\vec{\tau} = \vec{\mu} \times \vec{B}$	The torque $\vec{\tau}$ on a current loop in a magnetic field $\vec{B}$.
$\vec{\mu} = NI\vec{A}$	The magnetic dipole moment $\vec{\mu}$ as a function of the number of coils, N, the current, I, and oriented area of the loop $\vec{A}$.
$B = \frac{\mu_0}{2\pi}\frac{I}{r}$	Magnetic field B (in T) at a distance r (in m) from a long straight wire that carries a current I (in A).
$\oint \vec{B}.d\vec{l} = \mu_0 I_{\text{encl}} + \mu_0\varepsilon_0 \frac{d\Phi_E}{dt}$	<u>Ampère's law</u>: line integral of the magnetic field $\vec{B}$ around any closed loop equals μ_0 times the total net current I_{encl} enclosed by the loop.
$d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l} \times \hat{r}}{r^2}$	Biot-Savart Law: $d\vec{B}$ is the contribution to the magnetic field at some point P due to the current in the infinitesimal oriented line segment $d\vec{l}$ located at a distance r from P.
$\Phi_B = \vec{B}.\vec{A}$	Magnetic flux (in Wb or Tm^2) passing through a loop equals the product of the area of the loop times the perpendicular component of the uniform magnetic field $\vec{B}$ (direction of $\vec{A}$ is chosen perpendicular to the surface whose area is A).
$\Phi_B = \int \vec{B}.d\vec{A}$	Magnetic flux in case the field is not uniform.
$\varepsilon = -N\frac{d\Phi_B}{dt}$	<u>Faraday's law of induction:</u> The magnitude of the emf ε (in V) induced in a coil equals the time rate of change of the magnetic flux Φ_B (in Wb) through the loop times the number N of loops in the coil.
$\oint \vec{E}.d\vec{l} = -\frac{d\Phi_B}{dt}$	General law of <u>Faraday's law</u>: line integral of the electric field $\vec{E}$ is taken around the (closed) loop through which the magnetic flux Φ_B is changing.
$\varepsilon = -L\frac{dI}{dt}$ with $L = N\frac{\Phi_B}{I}$	Definition of self-inductance L (in H): Within a single coil (with N loops) a changing current I (in A) induces an opposing emf ε (in V), with L the coefficient of self-inductance (in H) of the coil and Φ_B the magnetic flux (in Wb) through the coil.
$U = \frac{1}{2}LI^2$	Energy stored in the inductor with inductance L when the current is given by I.

$u = \frac{1}{2}\frac{B^2}{\mu_0}$	Energy density in any magnetic field $\vec{B}$.
$\tau = \frac{L}{R}$	Time constant τ for LR-circuit.
$X_L = \omega L$	The reactance of an inductor X_L is the frequency ω multiplied by the inductance L, with $\omega = 2\pi f$.
$X_C = \frac{1}{\omega C}$	The reactance of a capacitor X_C is one over the frequency ω multiplied by the capacitance C, where $\omega = 2\pi f$.
$Z = \sqrt{R^2 + (X_L - X_C)^2}$	The impedance Z in as LRC-circuit as a function of the resistance R and the reactance of an inductor and a capacitor.
$\oint \vec{B} \cdot d\vec{A} = 0$	Gauss' Law for magnetism. 'No isolated magnetic monopoles exist'.
$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$	Poynting vector.
$\overline{S} = \frac{1}{2}\varepsilon_0 c E_0^2 = \frac{1}{2}\frac{c}{\mu_0}B_0^2 = \frac{E_0 B_0}{2\mu_0}$	Average magnitude of Poynting vector in terms of the maximum values E_0 and B_0.
$\overline{S} = \frac{E_{rms}B_{rms}}{\mu_0}$	Average magnitude of the Poynting vector in terms of the root mean square values E_{rms} and B_{rms}.
$P = \frac{F}{A} = \frac{1}{A}\frac{dp}{dt} = \frac{1}{Ac}\frac{dU}{dt} = \frac{\overline{S}}{c}$	Radiation pressure for fully absorbing material
$P = \frac{2\overline{S}}{c}$	Radiation pressure for fully reflecting material
$c = \lambda f$	The wavelength λ and the frequency *f* of EM waves are related to the speed of light *c*.
$Q(t) = Q_0 \cos \omega t \quad \text{with} \quad \omega = \frac{1}{\sqrt{LC}}$	Time evolution of the charge *Q* (in C) on the positive plate of the capacitor in an LC circuit (without resistance), with *C* the capacitance (in F) and *L* the inductance (in H).

Fundamental constants

Quantity	Symbol	Value
Speed of light in vacuum	c	3.00×10^{8} m s^{-1}
Charge on electron	e	1.60×10^{-19} C
Permittivity of free space	ε_0	8.85×10^{-12} C^2/N.m^2
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T.m/A
Acceleration due to gravity (average value at Earth's surface)	g	9.80 m/s^2
Refractive index vacuum	n	1
Refractive index air	n_a	1
Refractive index water	n_w	1.33
Refractive index glass	n_g	1.50