PHGN 200 Fall 2014: Exam III   Code: BCEEFD   Studio Time: 8   10   12   2   4
Name: ______________________________   ID: ________________

DO NOT OPEN THIS TEST PACKET UNTIL YOUR PROCTOR SAYS TO!

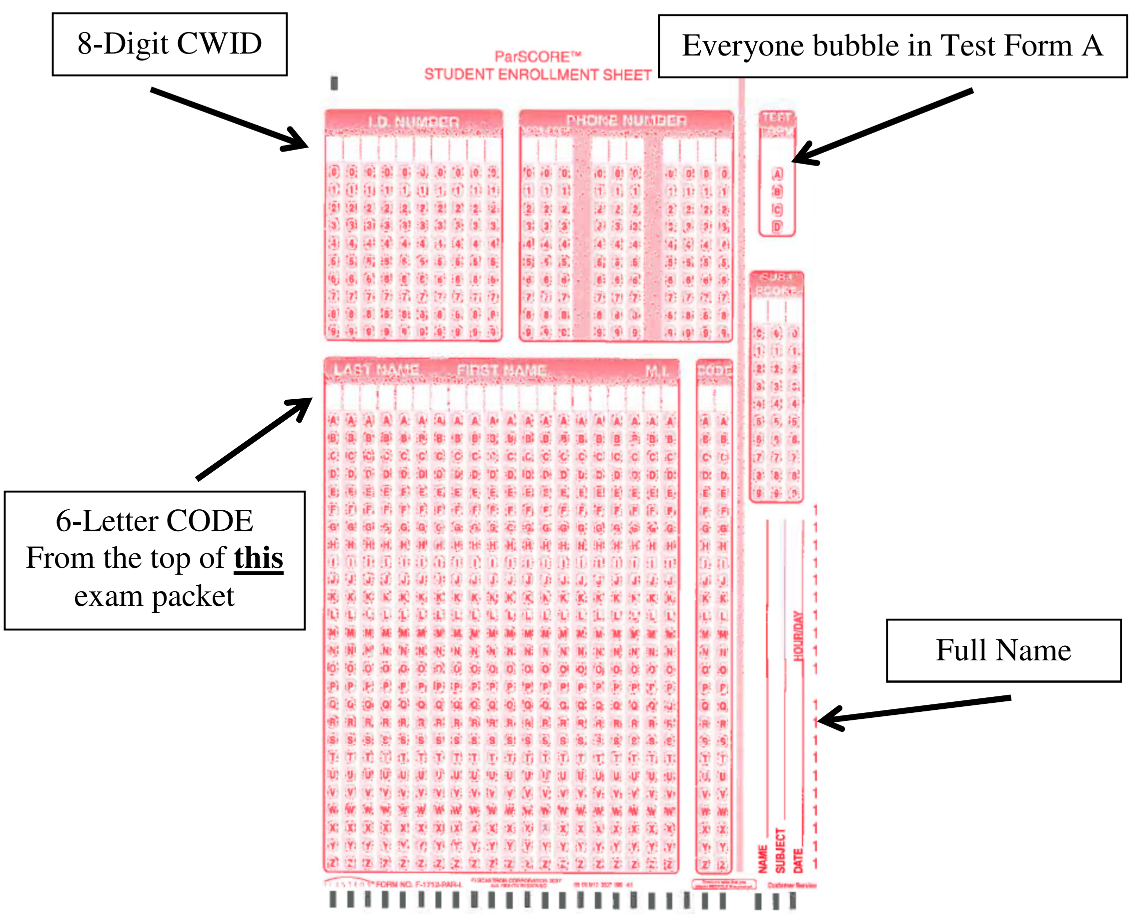
This exam is two hours long. Pace yourself so that you don't spend too much time on any single problem. There are 20 multiple choice questions on this test and 1 long problem. Once the test has begun, check to make sure all the pages are there. There is a total of 100 points.

Note: on some of the questions on this test, there are answers that are designed to catch common mistakes that you might make. So just because you get an answer that is the same as one on the test, it doesn't necessarily mean that it is correct.

Scantron Instructions

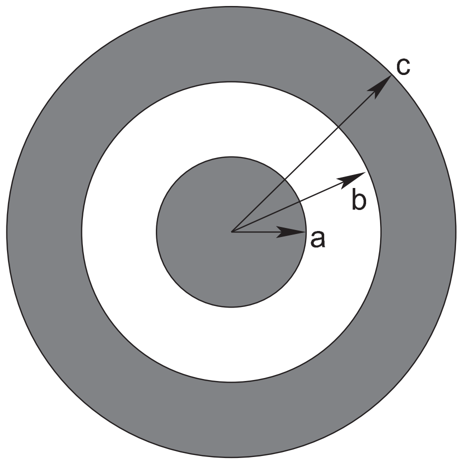
YOU MUST INDICATE ALL YOUR ANSWERS ON THE SCANTRON SHEET. No credit will be given for anything written on the exam, but you may write on the exam as much as you wish to work out your answers.

Fill in your scantron form as shown below. Make sure you fill in **all four things** that are required before the exam starts. Once the test has begun, take a few minutes to **TRIPLE CHECK** that you have bubbled in your **CWID** and your **CODE** correctly. If either one of those is not correct, we won't be able to get you your grade.



Name:

4 point(s)
A long coaxial cable consists of two concentric conductors with dimensions $a = 1.50$ cm, $b = 5.50$ cm and $c = 6.50$ cm. There are equal and opposite uniform currents of 3.00 A in the conductors. Find the magnitude of the magnetic field at a distance of 0.45 cm from the center axis.



(in T*)*

1. **A**◯ 5.71×10^{-6} **B**◯ 8.28×10^{-6} **C**◯ 1.20×10^{-5} **D**◯ 1.74×10^{-5} **E**◯ 2.52×10^{-5}

---

4 point(s)
It is known that birds can detect the earth's magnetic field, but the mechanism of how they do this is not known. It has been suggested that perhaps they detect a motional emf as they fly north to south, but it turns out that the induced voltages are small compared to the voltages normally encountered in cells, so this is probably not the mechanism involved.

To check this out, calculate the induced voltage for a wild goose with a wingspan of 1.4 m at level flight due south at 13 m/s at a point where the earth's magnetic field is 5×10^{-5} T directed downward from horizontal by 16°. What would be the expected voltage difference across the goose' wingtips?

2. **A**◯ 0.087 mV
B◯ 0.87 mV
C◯ 0.25 mV
D◯ 0.13 mV
E◯ 0.91 mV

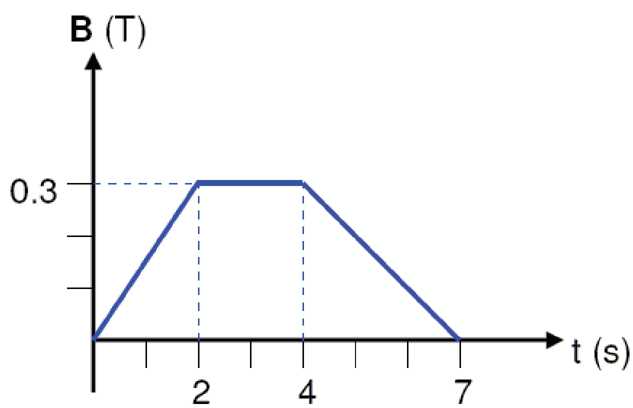
---

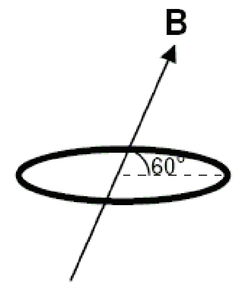
4 point(s)
A 2.60 m long rod rotates about an axis through one end and perpendicular to the rod, with a rotational frequency ω of 16.96 radians per second. The plane of rotation of the rod is perpendicular to a uniform magnetic field of 0.30 T. Calculate the magnitude of the ϵmf induced between the ends of the rod. *(in* V*)*

3. **A**◯ 1.26×10^{1} **B**◯ 1.47×10^{1} **C**◯ 1.72×10^{1} **D**◯ 2.01×10^{1} **E**◯ 2.35×10^{1}

---

8 point(s)
The magnetic field through a 10 turn, 0.15 m radius coil varies with respect to time according to the graph shown below. The field lines make an angle of 60^0 with respect to the coil plane.





What is the magnitude of the induced emf for the time interval 0 - 2 seconds?

$emf =$ *(in* V*)*

4. **A**◯ 6.36×10^{-2} **B**◯ 7.19×10^{-2} **C**◯ 8.13×10^{-2} **D**◯ 9.18×10^{-2} **E**◯ 1.04×10^{-1}

What is the direction of the induced current during this time interval?

▷
5. **A**◯ Counter-clockwise as seen from above **B**◯ Clockwise as seen from above
C◯ No current

---

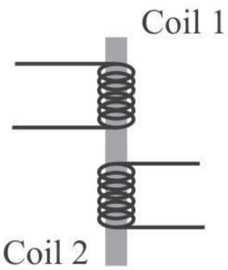
4 point(s)
A 18.0 cm long solenoid has 88 windings and a circular cross section of radius $a = 1.00$ cm. The solenoid goes through the center of a circular coil of wire with 69 windings and radius $b = 5.00$ cm. The current in the circular coil changes according to $i(t) = 3.0\ t^2 + 2.5\ t$.

What is the mutual inductance of the coil and solenoid?
(in H*)*

6. **A**◯ 1.00×10^{-5} **B**◯ 1.33×10^{-5} **C**◯ 1.77×10^{-5} **D**◯ 2.36×10^{-5} **E**◯ 3.13×10^{-5}

---

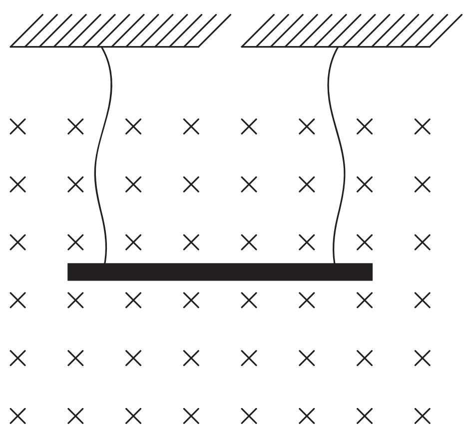
4 point(s)
The picture below shows a crude transformer, a device for transferring electrical energy from one circuit to another. Solenoid 1 is wrapped tightly around an iron bar, guaranteeing that any magnetic field produced by solenoid 1 will be transmitted exactly down to solenoid 2. Solenoid 1 has 180 turns and solenoid 2 has 180 turns. There's a typical 12 V car battery hooked up to the input coil. Calculate the rms voltage that will be induced in solenoid 2.



7. **A**◯ 12.00 V
B◯ 0 V
C◯ 8.49 V
D◯ 12.00 V

---

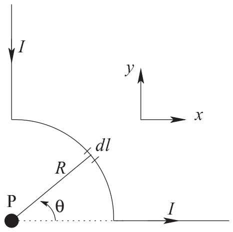
4 point(s)
A conducting bar of length 0.20 m and mass 48.0 g is suspended by a pair of flexible leads in a uniform 0.50 T magnetic field (directed into the page) as shown in the figure. What is the current required to remove the tension in the supporting leads?



(in A*)*

8. **A**◯ 4.71 **B**◯ 5.88 **C**◯ 7.35 **D**◯ 9.19 **E**◯ 1.15×10^1

12 point(s)
Consider the current-carrying segments of wire shown below.



The vector $d\vec{\ell}$ shown, used to calculate the magnetic field at point P, is given by

9. **A**◯ $d\vec{\ell} = R\cos\theta\, d\theta\hat{\imath} + R\sin\theta\, d\theta\hat{\jmath}$
B◯ $d\vec{\ell} = R\sin\theta\, d\theta\hat{\imath} + R\cos\theta\, d\theta\hat{\jmath}$
C◯ $d\vec{\ell} = R\sin\theta\, d\theta\hat{\imath} - R\cos\theta\, d\theta\hat{\jmath}$
D◯ $d\vec{\ell} = R\, d\theta\hat{\imath} - R\, d\theta\hat{\jmath}$
E◯ None of the above.

The r-vector used in the Biot-Savart law to calculate the magnetic field at point P due to the segment $d\vec{\ell}$ is

10. **A**◯ $-R\sin\theta\hat{\imath} - R\cos\theta\hat{\jmath}$
B◯ $R\theta\hat{\imath} + R\theta\hat{\jmath}$
C◯ $-R\cos\theta\hat{\imath} - R\sin\theta\hat{\jmath}$
D◯ $R\cos\theta\hat{\imath} + R\sin\theta\hat{\jmath}$
E◯ None of the above.

Calculate the *total* vector magnetic field at point P due to all segments of the wire shown.

11. **A**◯ $\vec{B} = \frac{\mu_0 I}{8R}(-\hat{k})$
B◯ $\vec{B} = \frac{\mu_0 I}{4R}\hat{k}$
C◯ $\vec{B} = \frac{\mu_0 I}{4R}(-\hat{k})$
D◯ $\vec{B} = \frac{\mu_0 I}{8R}\hat{k}$
E◯ None of the above.

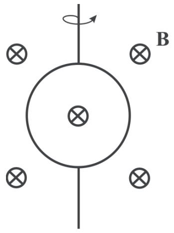
---

4 point(s)
When trying to determine the maximum magnetic field created by your 16-turn field coil in the Faraday's law lab, you measure the maximum current to be 0.1 ± 0.06 A, and the radius of your coil to be 0.06 ± 0.005 m. If these are the only uncertainties, what is the total uncertainty in the maximum magnetic field?

12. **A**◯ 5.189×10^{-6} **B**◯ 6.487×10^{-6} **C**◯ 8.108×10^{-6} **D**◯ 1.014×10^{-5} **E**◯ 1.267×10^{-5}

---

4 point(s)
We have N loops of wire of rotating about an axis with some angular speed ω. There is a uniform magnetic field of magnitude B pointing into the page. Different combinations of N, ω, and B will give us different induced voltages.



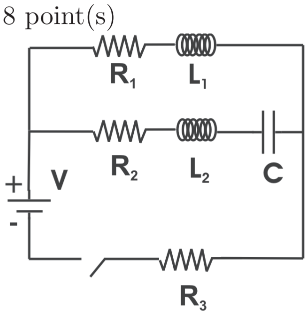
Rank the magnitudes of the peak voltages that will be generated in the following four scenarios.

I) B is 2 T, ω is 60 rad/s, and N is 20 loops.
II) B is 1 T, ω is 120 rad/s, and N is 20 loops.
III) B is 2 T, ω is 120 rad/s, and N is 10 loops.
IV) B is 4 T, ω is 15 rad/s, and N is 40 loops.

13. **A**◯ I = IV > II = III
B◯ I = II = III = IV
C◯ II = III > I > IV
D◯ IV > II > I > III
E◯ None of these are true

---

8 point(s)



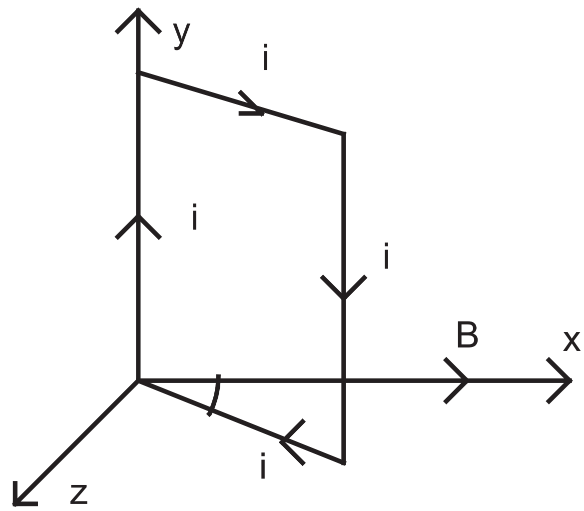
Consider the circuit shown in the figure above. The switch has been open for a very long time, and then we close it. Rank the magnitudes of the currents through resistors R_1, R_2, and R_3, from greatest to least, in the instant right after we close the switch. Assume that $R_1 > R_2 > R_3$.

14. **A**◯ $I_1 = I_2 = I_3$
B◯ $I_1 > I_3 > I_2$
C◯ $I_3 > I_1 > I_2$
D◯ $I_1 = I_3 > I_2$
E◯ None of the above

Rank the currents through the three resistors after the switch has been closed for a very long time.

15. **A**◯ $I_1 = I_3 > I_2$
B◯ $I_3 > I_1 > I_2$
C◯ $I_3 > I_2 > I_1$
D◯ $I_1 > I_2 > I_3$
E◯ None of the above

4 point(s)
The figure shows a rectangular loop of wire of 80 turns, 23.0 cm by 25.0 cm. It carries a current of 1.76 A and is hinged at one side. What is the magnitude of the torque that acts on the loop, if it is mounted with its plane at an angle of 24.0 degrees to the direction of **B**, which is uniform and equal to 0.70 T?

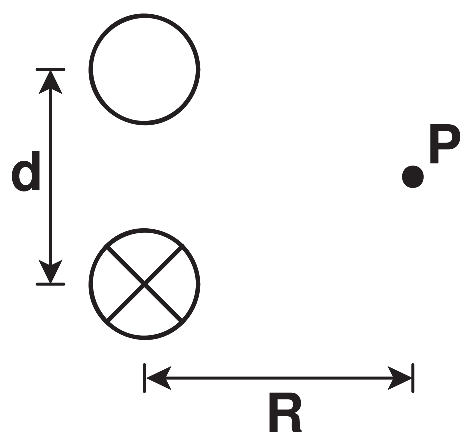


(in `N*m`*)*

16. **A**◯ 1.65 **B**◯ 2.20 **C**◯ 2.93 **D**◯ 3.89 **E**◯ 5.18

---

4 point(s)
Two long parallel wires are a center-to-center distance of 1.00 cm apart and carry equal anti-parallel currents of 6.10 A. Find the magnitude of the magnetic field at the point P which is equidistant from the wires. ($R =$ 7.00 cm).



(in `T`*)*

17. **A**◯ 1.81×10^{-6} **B**◯ 2.12×10^{-6} **C**◯ 2.48×10^{-6} **D**◯ 2.90×10^{-6} **E**◯ 3.39×10^{-6}

---

4 point(s)

An electron in J. J. Thomson's e/m apparatus moves perpendicular to a **B**-field along a circular path of radius 11.60 cm. If imposition of an **E**-field of 15.50 kV/m makes the path straight, what is the value of **B**?
(in `T`*)*

18. **A**◯ 6.3673×10^{-4} **B**◯ 7.4497×10^{-4} **C**◯ 8.7162×10^{-4} **D**◯ 1.0198×10^{-3} **E**◯ 1.1932×10^{-3}

---

4 point(s)
In the Superconducting Super Collider that was planned to have been built in Texas this past decade, protons would be bent by a magnetic field and would move in a circle of radius 13.48 km. Magnetic fields of magnitude 5.32 T would have been used to bend the protons. What is the magnitude of the momentum, **p**, of a proton that moves at a radius of 13.48 km in this field? You may assume that the magnetic field involved is perpendicular to the motion of the charges (that's the most efficient configuration).
(in `kg*m/s`*)*

19. **A**◯ 3.67×10^{-15} **B**◯ 4.88×10^{-15} **C**◯ 6.50×10^{-15} **D**◯ 8.64×10^{-15} **E**◯ 1.15×10^{-14}

---

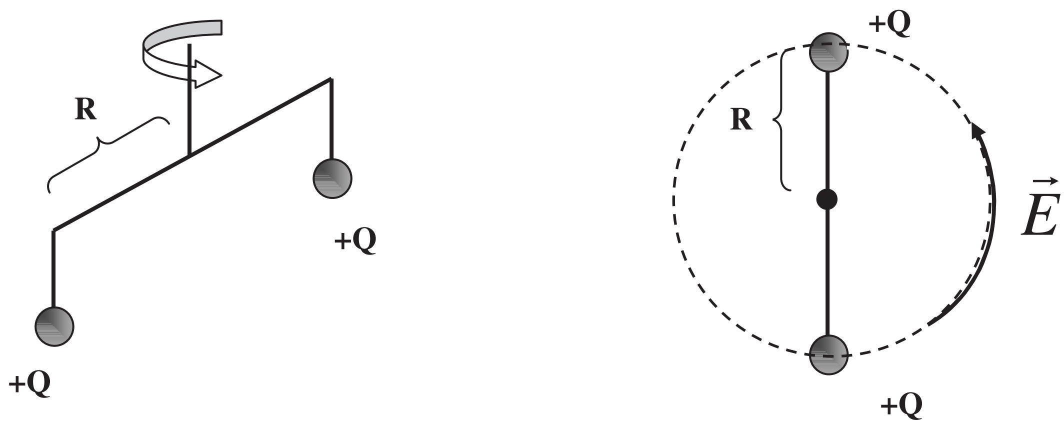
4 point(s)
A wire segment carrying a current I is bent into a cosine shape with period of 2π, i.e., $y = \cos(x)$ and the wire has length 4π in the $x-$direction. There is a magnetic field in the vicinity of the wire which points in the positive $z-$direction with a magnitude given by $B = B_0 x$. What is the magnitude of the $y-$component of the force on the wire segment?

20. **A**◯ $|F_y| = \left|16\pi^2 I B_o\right|$
B◯ $|F_y| = \left|8\pi^2 I B_o\right|$
C◯ $|F_y| = 0$
D◯ $|F_y| = |4\pi I B_o|$
E◯ $|F_y| = \left|\frac{I B_o}{4\pi^2}\right|$

Name ______________________ CWID ______________Studio: 8am 10am 12pm 2pm 4pm

(20 points total) In all parts of this problem, show and explain what you're doing. Write your algebraic answers in terms of the constants given.

The picture shows two balls hanging from a crossbar that's free to rotate (it's basically a mobile). Each ball has some positive charge **Q**. The crossbar is of total length 2**R**. There's a perspective view (left) and a top-down view (right). The arrow shows a possible rotation; it's free to rotate in either direction.



a) (5 points) We start out with everything stationary and with no external fields. Then, we turn on a magnetic field of strength **B** pointing upward (out of the page from the top-down view). It takes some time **t** for the field to ramp up. While the magnetic field is changing, there's a voltage induced on the loop of radius **R** that includes both charges. What is that voltage?

b) (5 points) That voltage comes from a circular electric field that gets induced by the changing magnetic field. Use what you know about how electric fields and voltages are related to figure out how strong the induced electric field is at the location of the charges. You may use **V** for the voltage instead of your answer from a.

c) (5 points) Given this field (let's call it **E** now), what will be the force on one of the balls, and what will be the total torque on the mobile?

d) (5 points) Use Lenz' law to figure out whether the balls will begin rotating clockwise or counterclockwise, viewed from above. Explain how you know. Note that the E-field shown on the picture is just an example; the direction may or may not be accurate.

(3 points, extra credit) When we started, nothing was moving. After we turned on the magnetic field, the balls started rotating. We know from mechanics that angular momentum has to be conserved no matter what; the "before" and "after" situations have to have the same total angular momentum. But this appears to violate that. How might we reconcile things? Hint: The only things in this problem are the mobile and the fields. You don't have to talk about the angular moment of the earth or anything like that. You might, however, be forced to conclude something surprising.

Physics 200: Fundamental Equations

Maxwell's Equations

Gauss's Law for Electric Field: $\oint \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{A}} = \frac{Q_{\text{encl}}}{\varepsilon_0} = 4\pi k Q_{\text{encl}}$; Electric Flux: $\Phi_E = \int \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{A}}$
Gauss's Law for Magnetic Field: $\oint \vec{\boldsymbol{B}} \cdot d\vec{\boldsymbol{A}} = 0$; Magnetic Flux: $\Phi_B = \int \vec{\boldsymbol{B}} \cdot d\vec{\boldsymbol{A}}$
Ampère/Maxwell: $\oint \vec{\boldsymbol{B}} \cdot d\vec{\boldsymbol{\ell}} = \mu_0 I_{\text{thru}} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$
Faraday's Law: $\mathcal{E}_{\text{induced}} = \oint (\vec{\boldsymbol{E}} + \vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}}) \cdot d\vec{\boldsymbol{\ell}} = -\frac{d\Phi_B}{dt}$

Fields, Forces, and Energy

Electric field: $d\vec{\boldsymbol{E}} = \frac{k\,dQ}{r^2}\hat{\boldsymbol{r}} = \frac{k\,dQ}{r^3}\vec{\boldsymbol{r}}$; $\quad \vec{\boldsymbol{F}}^{\text{elec}}_{\text{on q}} = q\vec{\boldsymbol{E}}_{\text{at q}}$;
Electric potential: $\Delta V = V_B - V_A = -\int_A^B \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{\ell}}$; $\quad E_x = -\frac{dV}{dx}$; $\quad dV = \frac{k\,dQ}{r}$
Electrostatic energy: $\Delta U_{\text{of q}} = q\,\Delta V$
Dielectrics: $\epsilon_{\text{in}} = \kappa_E \epsilon_0$; $C = \kappa_E C_0$
Magnetic field: $d\vec{\boldsymbol{B}} = \frac{\mu_0 I\, d\vec{\boldsymbol{\ell}} \times \hat{\boldsymbol{r}}}{4\pi r^2} = \frac{\mu_0 I\, d\vec{\boldsymbol{\ell}} \times \vec{\boldsymbol{r}}}{4\pi r^3}$;
Magnetic force: $d\vec{\boldsymbol{F}} = I\,d\vec{\boldsymbol{\ell}} \times \vec{\boldsymbol{B}}$; $\quad \vec{\boldsymbol{F}}^{\text{mag}}_{\text{on q}} = q\vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}}$
Magnetic dipole: $\vec{\boldsymbol{\mu}} = NI\vec{\boldsymbol{A}}$; $\quad \vec{\boldsymbol{\tau}} = \vec{\boldsymbol{\mu}} \times \vec{\boldsymbol{B}}$; $\quad U = -\vec{\boldsymbol{\mu}} \cdot \vec{\boldsymbol{B}}$

Circuits

Resistors: $V = IR$; $\quad dR = \frac{\rho\,dL}{A}$; $\quad R_{series} = \sum_i R_i$; $R_{parallel} = \left(\sum R_i^{-1}\right)^{-1}$
Capacitors: $C = \frac{Q}{|\Delta V|}$; $U_{\text{C}} = \frac{1}{2}C(\Delta V)^2$; $C_{series} = \left(\sum_i C_i^{-1}\right)^{-1}$; $C_{\text{parallel}} = \sum_i C_i$; $C = \kappa_E C_0$
Current: $I = \frac{dQ}{dt} = n|q|v_{\text{d}}A$; $\vec{\boldsymbol{J}} = nq\vec{\boldsymbol{v}}_{\text{d}}$
Power: $P = I\,\Delta V$
Kirchhoff's Laws: $\sum_{\text{Closed loop}} \Delta V_i = 0$; $\quad \sum I_{\text{in}} = \sum I_{\text{out}}$
RC Circuits: $Q(t) = Q_{\text{final}}\left(1 - e^{-t/RC}\right)$; $\quad Q(t) = Q_{\text{initial}} e^{-t/RC}$
AC Circuits: $X_{\text{C}} = \frac{1}{\omega C}$; $V_{\text{C}} = IX_{\text{C}}$; $Z = \sqrt{R^2 + X_{\text{C}}^2}$; $V = IZ$; $V_{rms} = V_{peak}/\sqrt{2}$
Inductors: $\mathcal{E}_{\text{ind}} = -L\frac{dI}{dt}$; $\quad L = N\Phi_{\text{B, 1 turn}}/I$; $U_{\text{B}} = \frac{1}{2}LI^2$
Inductance: $M_{12} = N_2 \Phi_{\text{B, one turn of 2}}/I_{\text{in 1}}$ $\qquad \mathcal{E}_1 = -M_{12}\frac{dI_2}{dt}$
LR Circuits: $I(t) = I_{\text{final}}\left(1 - e^{-t/(L/R)}\right)$; $I(t) = I_{\text{initial}} e^{-t/(L/R)}$

Electromagnetic Waves Optics and Field Energy Density

Field Energy/Momentum: $u_E = \frac{1}{2}\varepsilon_0 E^2$; $\quad u_B = \frac{1}{2\mu_0}B^2$; $\quad p = U/c$
Wave Properties: $\quad v = \lambda f$; $\quad k = 2\pi/\lambda$; $\quad \omega = 2\pi f$; $\quad E = cB$
Intensity: $\vec{\boldsymbol{S}} = \frac{1}{\mu_0}\left(\vec{\boldsymbol{E}} \times \vec{\boldsymbol{B}}\right)$; $\quad I = |\vec{\boldsymbol{S}}|_{avg} = c\frac{1}{2}\varepsilon_0 E_{\text{m}}^2 = \frac{P_{\text{av}}}{A}$
Reflection/Refraction: $v_{\text{in material}} = c/n_1$; $\quad \theta_{\text{inc}} = \theta_{\text{ref}}$; $\quad n_1 \sin(\theta_{\text{inc}}) = n_2 \sin(\theta_{\text{trans}})$
Interference: Constructive: $\Delta r = m\lambda$; Destructive: $\Delta r = (m + 1/2)\lambda$
Bragg: $2d\sin(\theta) = m\lambda$; Double-slit: $d\sin(\theta) = m\lambda$ or $dy_m/R = m\lambda$ for small θ

Additional Information/Useful Constants

Electric fields: $E_{\text{inf sheet}} = \frac{\sigma}{2\varepsilon_0}$; $\quad E_{\text{inf line}} = 2k\lambda/r$; $\quad \vec{\boldsymbol{E}}_{\text{charged ring}} = \frac{kQx}{(x^2+a^2)^{3/2}}\hat{\boldsymbol{\imath}}$; $\quad C_{\text{parallel plate}} = \frac{\varepsilon_0 A}{d}$
Magnetic fields: $B_{\text{infinite wire}} = \frac{\mu_0 I}{2\pi r}$; $B_{\text{solenoid}} = \mu_0 n I$; $L_{\text{solenoid}} = \mu_0 n^2 A \ell$; $B_{\text{current loop}} = \frac{\mu_0 N I R^2}{2(x^2+R^2)^{3/2}}$
Fundamental Charge: $e = 1.602 \times 10^{-19}$ C; $\quad$ Electron Mass: $m_{\text{e}} = 9.11 \times 10^{-31}$ kg
Proton Mass: $m_{\text{p}} = 1.673 \times 10^{-27}$ kg;
$k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 (\text{N}\cdot\text{m}^2/\text{C}^2)$ $\quad \epsilon_0 = 8.85 \times 10^{-12}\frac{\text{F}}{\text{m}}$; $\quad \mu_0 = 4\pi \times 10^{-7}\frac{\text{Tm}}{\text{A}} = 1.2566 \times 10^{-6}\frac{\text{Tm}}{\text{A}}$;
$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8$ m/s;