Chapter 20

True or false?

1. It's impossible to place a charge on an insulator, because no current can flow in an insulator. F. Charges can be transferred from the surface of one insulator to the surface of another insulator (by friction, for example) without a current flowing within the insulator. (And another thing: it's not impossible for a current to flow within an insulator, just very difficult; that is, it takes an extremely high voltage, and would result in extreme damage to the insulator.)

2. In an electric field, there is only a force at the field lines; between the field lines there is no force. F. In a contour map, only certain heights are indicated by the contour lines; the "in-between" heights are still there, but they are not indicated. Similarly, field lines are meant to give one a sense for the strength and direction of the field at various points in space. The field exists everywhere in space, but the field lines represent the field only at certain points.

3. The electric field inside a conductor at equilibrium is zero. T. If a field is applied to a "blob" of a conductor, then free charges inside the conductor would flow to the surface of the conductor in such a way that the net field inside the conductor would be zero. The time needed for this process to occur is a very small fraction of a second. (If the conductor is in the form of a loop of wire, and the applied electric field is just so (for example, if it were created by connection of the loop of wire to a battery), then it could be that equilibrium would "never" be reached; that is, a current could flow for a long time (until the battery is discharged).

CP 57 In a simple model of the hydrogen atom, the electron moves in a circular orbit of radius 0.053 nm around a stationary proton. How many revolutions per second does the electron make?
A small charged bead has a mass of 1.0 g. It is held in a uniform electric field of magnitude \( E = 200,000 \text{ N/C} \), directed upward. When the bead is released, it accelerates upward with an acceleration of \( 20 \text{ m/s}^2 \). What is the charge on the bead?

\[
F = \frac{Kq_1q_2}{r^2} = ma
\]

\[
\frac{Ke^2}{r^2} = \frac{mv^2}{r} \quad \Rightarrow \quad \text{solve for } v
\]

\[
v^2 = \frac{Ke^2}{mr}
\]

\[
= \frac{(9 \times 10^9)(1.6 \times 10^{-19})^2}{(9.11 \times 10^{-31})(0.053 \times 10^{-9})}
\]

\[
v^2 = 4.8 \times 10^{12}
\]

\[
v = 2.2 \times 10^6 \text{ m/s}
\]

The circumference of the electron's orbit is \( 2\pi r \), so the time needed for one orbit is

\[
distance = speed \times time
\]

\[
2\pi r = vt
\]

\[
t = \frac{2\pi r}{v}
\]

\[
= \frac{2\pi (0.053 \times 10^{-9})}{2.2 \times 10^6}
\]

\[
t = 1.5 \times 10^{-16} \text{ s}
\]

The number of revolutions per second is

\[
\frac{1}{1.5 \times 10^{-16}} = 6.6 \times 10^{15} \text{ revolutions/s}
\]
Chapter 21

True or false?

1. Equipotentials are surfaces in space where the electrical potential is equally spaced. **F.** Equipotentials are surfaces in space on which the potential is constant.

2. Equipotentials are always concentric spheres. **F.** Only in the simplest situations (a single point charge, a spherically symmetric charge distribution) are they concentric spheres.

3. When the plates of a parallel-plate capacitor are moved apart, the voltage between the plates decreases. **F.** If the battery that charged the capacitor stays connected to the plates while they are moved apart, then the voltage between the plates stays constant. On the other hand, if the battery charges the plates, then is disconnected from the plates, and then the plates are moved apart, the voltage between the plates actually increases. You can understand this by looking at the formulas $Q = CV$ and $C = \varepsilon_0 A/d$. As the distance between the plates increases, the capacitance decreases, by the second
The electric field strength is 50,000 V/m inside a parallel-plate capacitor with a 2.0 mm spacing. A proton is released from rest at the positive plate. What is the proton's speed when it reaches the negative plate?

\[
\Delta K = -\Delta U
\]

\[
\frac{1}{2}mv^2 - 0 = -q\Delta V
\]

\[
v^2 = -\frac{2qEd}{m}
\]

\[
U^2 = (1.6 \times 10^{-19}) (50,000) (2 \times 10^{-3})^2
\]

\[
v^2 = 1.916 \times 10^{10}
\]

\[v = 1.4 \times 10^5 \text{ m/s}
\]

Two 2.0-cm-diameter disks spaced 2.0 mm apart form a parallel-plate capacitor. The electric field between the disks is \(5.0 \times 10^5\) V/m. (a) Determine the voltage across the capacitor. (b) Determine the charge on each disk. (c) An electron is launched from the negative plate. It strikes the positive plate at a speed of \(2.0 \times 10^7\) m/s. Determine the electron's speed as it left the negative plate.

(a) \[\Delta V = Ed\]

\[= (5 \times 10^5)(2 \times 10^{-3})\]

\[= 1000 \text{ V}
\]

(b) First determine the capacitance:

\[C = \varepsilon_0 A = (8.85 \times 10^{-12}) \pi (1 \times 10^{-2})^2\]
(a) \[ \Delta V = Ed \]
\[ = (5 \times 10^5)(2 \times 10^{-3}) \]
\[ = 1000 \text{V} \]

(b) First determine the capacitance:
\[ C = \frac{\varepsilon_0 A}{d} = \frac{(8.85 \times 10^{-12}) \pi (1 \times 10^2)^2}{2 \times 10^{-3}} \]
\[ C = 1.39 \times 10^{-12} \text{F} = 1.4 \text{pF} \]

The charge on each disk is
\[ Q = C \Delta V = (1.39 \times 10^{-12})(1000) \]
\[ Q = 1.4 \times 10^{-9} \text{C} = 1.4 \text{nC} \]

(c) As in CP65, use conservation of energy:
\[ \Delta K + \Delta U = 0 \]
\[ \Delta K = -\Delta U \]
\[ \frac{1}{2} m (2.0 \times 10^7)^2 - \frac{1}{2} m v^2 = g \Delta V = g Ed \]
\[ m [4 \times 10^{14} - v^2] = 2g Ed \]
\[ 4 \times 10^{14} - v^2 = \frac{2g Ed}{m} \]
\[ v^2 = 4 \times 10^{14} - \frac{2g Ed}{m} \]
\[ = 4 \times 10^{14} - \frac{2(1.6 \times 10^{-19})(5 \times 10^5)(2 \times 10^{-3})}{9.11 \times 10^{-31}} \]
\[ = 4 \times 10^{19} - 3.51 \times 10^{14} \]
\[ v^2 = 0.487 \times 10^{14} \]
\[ v = 7.0 \times 10^6 \text{m/s} \]

Chapter 22

True or false?
1. When two identical light bulbs are connected in series to
a battery, the one closer to the negative terminal of the battery is brighter, because the electrons reach this light bulb first. F. Electrons move simultaneously in all points of the series circuit, so electrons flow in both light bulbs at the same time. The light bulbs are equally bright.

2 When two identical light bulbs are connected in series to a battery, the one closer to the negative terminal of the battery is brighter, because some of the current is used up in the first light bulb, so there is not as much to flow through the second one. F. Current is NOT used up in a series circuit; the technical term for this is the principle of conservation of current (which logically derives from the principle of conservation of charge). Potential energy is used up in each light bulb. The light bulbs are equally bright.

3 Longer wires have less resistance than shorter wires, because the electrons have more room to spread out in a longer wire. F. The resistance of a wire is proportional to the length of the wire, so longer wires have more resistance than shorter wires of the same material and same cross-sectional area.

A 60 W bulb and a 100 W bulb are connected in series to a battery. Which is brighter?

Determine the resistance of each bulb. Saying a light bulb is "a 60-W bulb" means that when a 120 V potential difference is across the bulb, it dissipates 60 W of power. Thus, if they were connected in parallel, the 100 W bulb would be brighter. But they are NOT connected in parallel; they are connected in series.

Back to calculating the resistances of the bulbs; for the 60 W bulb,
An electric eel develops a potential difference of 450 V, driving a current of 0.80 A for a 1.0 ms pulse. For this pulse, determine (a) the power, (b) the total energy, and (c) the total charge that flows.

(a) \[ P = VI = (450)(0.8) = 360 \text{ W} \]
(b) \[ E = Pt = (360)(1 \times 10^{-3}) = 0.36 \text{ J} \]
(c) \[ Q = It = (0.8)(1 \times 10^{-3}) = 0.8 \text{ mC} \]

Air isn't a perfect insulator, but it has a very high resistivity. Dry air has a resistivity of about \(3 \times 10^{13} \Omega \cdot \text{m}\). A capacitor has square plates 10 cm on a side separated by 1.2 mm of dry air. If the capacitor is charged to 250 V, what fraction of the charge will flow across the air gap in 1 minute?
Make the approximation that the potential difference doesn’t change as the charge flows.

Pretend that the air space between the capacitor plates is a “wire”. Then the resistance of this wire is:

\[ R = \frac{\rho L}{A} = \frac{(3 \times 10^{13})(1.2 \times 10^{-3})}{(10 \times 10^{-2})^2} \]
\[ R = 3.6 \times 10^{12} \Omega \quad \text{(very large!)} \]

\[ C = \frac{\varepsilon_0 A}{d} = \frac{(8.85 \times 10^{-12})(10 \times 10^{-2})^2}{(1.2 \times 10^{-3})} \]
\[ C = 7.4 \times 10^{-11} \text{ F} \]

\[ Q = C \Delta V = (7.38 \times 10^{-11})(250) \]
\[ Q = 1.84 \times 10^{-8} \text{ C} \]

\[ I = \frac{\Delta V}{R} = \frac{250}{3.6 \times 10^{12}} = 6.9 \times 10^{-11} \text{ A} \]

Charge leakage in 1 minute is

\[ \Delta Q = I \Delta t = (6.9 \times 10^{-11})(60 \text{ s}) \]
\[ \Delta Q = 4 \times 10^{-9} \text{ C} \]

Fraction of charge that leaks in 1 minute is

\[ \frac{\Delta Q}{Q} = \frac{4.2 \times 10^{-9}}{1.84 \times 10^{-8}} = 2.3 \times 10^{-1} \approx 23\% \]

Chapter 23
True or false?
1. Two identical light bulbs connected in series to a battery will be brighter than the same light bulbs connected in parallel to the same battery, because the full current flows through them when they are in series, whereas in parallel each light bulb gets only part of the current. \textbf{F.} The effective resistance of the two bulbs in series is \textbf{more} than the resistance of each bulb in parallel. Thus, more current flows through each bulb in parallel than the two bulbs in series, and therefore the power dissipated by each bulb in parallel is more than the power dissipated by both bulbs in series.
2. Two identical light bulbs connected in parallel to a battery will consume more power than the same light bulbs connected in series to the same battery, because more current will flow when they are in parallel. \textbf{T}, as explained in question 1.
3. Connecting more resistors in series increases the effective resistance, whereas connecting more resistors in parallel decreases the effective resistance. \textbf{T}, as you can see by examining the formulas for effective resistance of resistors in series and parallel.

CP 28  For the given circuit, determine the values of $\Delta V_{14}$, $\Delta V_{24}$, and $\Delta V_{34}$.

\[
\begin{align*}
1 \text{ A} & \quad V_1 = 5 \text{ V} \\
\text{0.5 A} & \quad V_2 = 2 \times 5 \text{ V} \\
V_3 & = 1 \times 2 \times 5 \text{ V}
\end{align*}
\]
Strategiv: first determine the total (effective) resistance of the circuit:
\[
R = \left( \left( \left( \frac{1}{5} + \frac{1}{5} \right)^{-1} + \frac{1}{5} \right)^{-1} + \frac{1}{5} \right)^{-1} + \frac{1}{5} + 5 = 10.5 \Omega
\]

Thus, the current from the battery is
\[
I = \frac{V}{R} = \frac{10V}{10.5 \Omega} = 1A
\]

Now assign potentials to each of the key points of the circuit, as we did in class. (See diagram above.)

Finally:
\[
\Delta V_{14} = 5V \\
\Delta V_{24} = 2.5V \\
\Delta V_{34} = 1.25V
\]

Exercise:
Determine the equivalent resistance of the circuit.
Also determine the current that flows from the battery, and the total power dissipated by the circuit.

**Solution:** The effective resistance of the circuit is

\[
R = \left\{\left(\frac{10^{-1} + 10^{-1} + 10^{-1}}{10} + 10 + 10\right)^{-1} + 10^{-1} + 10^{-1}\right\}^{-1}
\]

\[
= \left\{\left(\frac{10}{3} + \frac{20}{3} + \frac{20}{3}\right)^{-1} + \frac{1}{10} + \frac{1}{10}\right\}^{-1}
\]

\[
= \left\{\frac{2}{70} + \frac{2}{70}\right\}^{-1}
\]

\[
= \left\{\frac{2}{70}\right\}^{-1}
\]

\[
= \frac{70}{2}
\]

\[
R = 4.18 \Omega
\]

The current from the battery is

\[
I = \frac{10V}{R} = \frac{10}{4.18} = \frac{170}{70} = 2.43 \text{ A}
\]

The power dissipated in the circuit is

\[
P = I^2R = \left(\frac{17}{7}\right)^2 \left(\frac{70}{17}\right) = 170 \text{ W}
\]

Chapter 24

True or false?

1. Only current in a loop of wire creates a magnetic field; current in a straight line produces magnetic forces, but not a magnetic field. **F.** Every electric current produces a magnetic field; if another charged particle should be moving so that its motion is not parallel to the magnetic field, then the particle
In the Bohr model of the hydrogen atom, the electron moves in a circular orbit of radius \(5.3 \times 10^{-11}\) m with a speed of \(2.2 \times 10^6\) m/s. Determine the magnetic field at the centre of a hydrogen atom due to the motion of the electron.

In effect, the motion of the electron in a circle forms a current. We can use the formula

\[
B = \frac{\mu_0 NI}{2R}
\]

for the magnetic field at the centre of a current loop, but first we have to calculate the current due to the electron's motion, using

\[
I = \frac{\Delta Q}{\Delta t} = \frac{\text{charge of the electron}}{\text{time for one orbit}}
\]

The time needed for one orbit is

\[
\Delta t = \frac{\text{distance}}{\text{speed}} = \frac{2\pi R}{v}
\]

Therefore,

\[
I = \frac{e}{\Delta t} = \frac{e}{2\pi R/v} = \frac{ev}{2\pi R}
\]

Since we consider the time for ONE orbit, we can think of the electron's motion as a "loop of wire" with ONE turn; i.e., \(N = 1\). Thus,

\[
R = \mu_0 I = \mu_0 \frac{ev}{2\pi R}
\]
\[ B = \frac{\mu_0 I}{2R} = \frac{\mu_0 \cdot e_v}{2R \cdot 2\pi R} \]
\[ = \frac{\mu_0 e_v}{4\pi R^2} \]
\[ = \frac{(4\pi \times 10^{-7})(1.6 \times 10^{-9})(2.2 \times 10^6)}{4\pi (5.3 \times 10^{-11})^2} \]
\[ B = 12.5 \text{ T} \]

CP 25  The microwaves in a microwave oven are produced in a special tube called a magnetron. The electrons orbit in a magnetic field at a frequency of 2.4 GHz, and as they do so they emit 2.4 GHz electromagnetic waves. What is the strength of the magnetic field?

I.e., they are asking for the strength of the magnetic field that the electrons orbit in, NOT the magnetic field that is part of the electromagnetic wave.

\[ F = ma \]
\[ qvB = \frac{mv^2}{r} \]
\[ B = \frac{mv}{qr} \]
\[ = \frac{m}{q} \left( \frac{v}{r} \right) \]
\[ = \frac{m \cdot 2\pi f}{q} \]
\[ = \frac{9.11 \times 10^{-31}}{1.6 \times 10^{-19}} \cdot 2\pi \cdot (2.4 \times 10^9 \text{ Hz}) \]
\[ B = 0.086 \text{ T} \]
\[ B = 86 \text{ mT} \]
CP 59 A long straight wire with a linear mass density of 50 g/m is suspended by threads, as shown in the figure. There is a uniform magnetic field pointing vertically downward. A 10 A current in the wire experiences a horizontal magnetic force that deflects it to an equilibrium angle of 10°. Determine the strength of the magnetic field.

Consider a 1m-length of wire. The mass of this length of wire is
\[50 \text{ g} \cdot 1 \text{ m} = 50 \text{ g} = 0.050 \text{ kg}\]

Draw a free-body diagram for this 1m length of wire:

Since the wire is at rest, the net force on the wire is 0.

Thus:

\[T \sin \theta - F = 0\]
\[T \cos \theta - mg = 0\]

which means:

\[\frac{T \sin \theta}{T \cos \theta} = \frac{F}{mg}\]

Dividing:

\[\tan \theta = \frac{F}{mg} \quad \rightarrow \quad F = mg \tan \theta\]

But, \( F = ILB \), and \( L = 1 \text{ m} \), so

\[F = mg \tan \theta\]

\[\Rightarrow IBL = mg \tan \theta\]

\[B = \frac{mg \tan \theta}{IL}\]
Chapter 25

True or false?
1 A changing magnetic field always induces a current in a nearby loop of wire. F. A current will be induced only if the magnetic flux through the loop of wire is changing; the flux will not change if the magnetic field is changing but is perpendicular to the axis of the loop (the flux through the loop will remain 0 even as the magnetic field changes; think of rain falling through a window that is oriented in various directions).
2 Faraday's law states that a current in a loop of wire induces a changing magnetic flux through the loop. F. It's the other way around: Faraday's law states that a changing magnetic flux through a loop of wire induces an emf in the loop of wire (which then creates an electric current in the wire as long as it is a closed conducting loop).
3 Electromagnetic waves are called transverse because the electric and magnetic fields are translated into one another as the wave moves. F. Electric and magnetic fields are NOT translated into one other in an electromagnetic wave. An electromagnetic wave is called transverse because the motion of the wave is perpendicular to the (moving) plane in which the electric and magnetic fields oscillate. (See the diagram on page 830 of the textbook.)

CP 28 A radio antenna broadcasts a 1.0 MHz radio wave with 25 kW of power. Assume that radiation is emitted uniformly in all directions. (a) Determine the wave's intensity 30 km from the antenna. (b) Determine the electric field amplitude at this
distance.

\( (a) \quad I = \frac{P}{4\pi r^2} = \frac{25,000}{4\pi (30,000)^2} \quad \text{W/m}^2 \)

\[ I = 2.21 \times 10^{-6} \quad \text{W/m}^2 \]

\( (b) \quad I = \frac{1}{2} C E_0 E_0^2 \)

\[ E_0^2 = \frac{2I}{C E_0} \]

\[ = \frac{2 \cdot 2.21 \times 10^{-6}}{(3 \times 10^8)(8.85 \times 10^{-12})} \]

\[ E_0^2 = 0.166 \times 10^{-2} \]

\[ E_0 = 0.04 \quad \text{V/m} \]

---

**CP 30** The intensity of a polarized electromagnetic wave is 10 W/m². Determine the intensity after passing through a polarizing filter whose axis makes the following angles with the plane of polarization. (a) 0° (b) 30° (c.) 45° (d) 60° (e) 90°

\[ I_{\text{transmitted}} = I_{\text{incident}} (\cos \theta)^2 \]

<table>
<thead>
<tr>
<th>( I_{\text{incident}} )</th>
<th>( \theta )</th>
<th>( \cos \theta )</th>
<th>( (\cos \theta)^2 )</th>
<th>( I_{\text{transmitted}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 W/m²</td>
<td>0°</td>
<td>1</td>
<td>1</td>
<td>10 W/m²</td>
</tr>
<tr>
<td>10 W/m²</td>
<td>30°</td>
<td>( \sqrt{3}/2 )</td>
<td>3/4</td>
<td>7.5 W/m²</td>
</tr>
<tr>
<td>10 W/m²</td>
<td>45°</td>
<td>( \sqrt{2}/2 )</td>
<td>1/2</td>
<td>5 W/m²</td>
</tr>
<tr>
<td>10 W/m²</td>
<td>60°</td>
<td>1/2</td>
<td>1/4</td>
<td>2.5 W/m²</td>
</tr>
<tr>
<td>10 W/m²</td>
<td>90°</td>
<td>0</td>
<td>0</td>
<td>0 W/m²</td>
</tr>
</tbody>
</table>

---

**CP 60** A TMS (transcranial magnetic stimulation) device creates very rapidly changing magnetic fields. The field near a typical pulsed-field machine rises from 0 T to 2.5 T in 200 µs. Suppose a technician holds his hand near the device so that the axis of his 2.0-cm-diameter wedding ring is parallel to the field. (a) Determine the emf induced in the ring. (b) The wedding ring is gold and has a cross-sectional area of 4.0
mm²; determine the induced current. (The resistivity of gold is $2.21 \times 10^{-8} \, \Omega \cdot m$.) (Can you see why TMS technicians are advised to remove all jewelry?)

By Faraday's law,

$$
\mathcal{E} = \left| \frac{\Delta \Phi}{\Delta t} \right| = A \cos \theta \left| \frac{\Delta B}{\Delta t} \right|
$$

$$
A = \pi r^2 = \pi (1 \text{ cm})^2 = \pi (0.01 \text{ m})^2 = 3.14 \times 10^{-4} \text{ m}^2
$$

$$
\theta = 0^\circ \Rightarrow \cos \theta = 1
$$

$$
\left| \frac{\Delta B}{\Delta t} \right| = \frac{2.5 T}{200 \mu s} = \frac{2.5}{200 \times 10^{-6}} = 1.25 \times 10^4 \text{ T/s}
$$

(a) \quad \mathcal{E} = A \cos \theta \left| \frac{\Delta B}{\Delta t} \right| = 3.93 \text{ V}

(b) The resistance of the ring is

$$
R = \frac{\rho L}{A} = \frac{(2.2 \times 10^{-8})(2\pi)(1 \text{ cm})}{4 \text{ mm}^2}
$$

$$
= \frac{(2.2 \times 10^{-8})(2\pi)(10^{-3})}{4 \times 10^{-6}}
$$

$$
R = 3.47 \times 10^{-4} \, \Omega
$$

The current induced in the ring is

$$
I = \frac{\mathcal{E}}{R} = \frac{3.93}{3.47 \times 10^{-4}} = 1.13 \times 10^4 \, \text{A}
$$

A huge current! The power dissipated is about

$$
45 \text{ kW}, \text{ which will badly burn the person's hand.}
$$

Chapter 26

True or false?
1  A transformer changes voltage to current and vice versa. \text{F.}

A transformer enables an AC current in one loop of wire to induce an AC current in a nearby loop of wire. By adjusting the number of turns in the primary and secondary loops of wire, the voltage in the secondary can be made larger or smaller
than the voltage in the primary. Similarly, the current in the secondary can be made larger or smaller than the current in the primary.

2. The main difference between a ground fault circuit interrupter and a circuit breaker is that the former detects ground faults and the latter detects short circuits. F. A ground fault is a type of short circuit. A circuit breaker breaks a circuit when the current increases to beyond 15 A (typically), whereas a ground fault circuit interrupter breaks a circuit when the current increases to beyond about 5 mA.

3. AC is much better than DC, because motors and generators cannot work with DC. F. There are motors and generators that work with DC, just as other types of motors and generators work with AC. AC current is used for household applications because it is easy using transformers to increase the voltage to very high levels so that it can be transmitted across country with minimal power loss, and then transformed back down to safe levels for use in homes.

CP 14  A science hobbyist has purchased a surplus power-pole transformer that converts 7.2 kV from neighbourhood distribution lines into 120 V for homes. He connects the transformer "backward," plugging the secondary coil into a 120 V outlet. Determine the rms voltage induced at the primary coil.

Connecting the transformer "normally" makes it act as a "step-down" transformer. Connecting it backwards makes it act as a "step-up" transformer with the same ratio, so the rms voltage at the primary (run backwards) is 7.2 kV.

\[
\text{Normal operation:} \\
\text{Input} \quad \begin{array}{c} 7.2 \text{kV} \\
\end{array} \quad \begin{array}{c} \text{transformer} \\
\end{array} \quad 120 \text{V} \quad \text{Output}
\]
A step-down transformer converts 120 V to 24 V, which is connected to a load of resistance 8.0 Ω. Determine the resistance "seen" by the power supply connected to the primary coil of the transformer.

\[ \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{24}{120} = \frac{1}{5} \]

In the secondary circuit, \( I_2 = \frac{V_2}{R} = \frac{24}{8} = 3 \text{ A} \).

Thus, the current in the primary is

\[ \frac{I_1}{I_2} = \frac{N_2}{N_1} \quad \Rightarrow \quad I_1 = \left( \frac{N_2}{N_1} \right) I_2 = \left( \frac{1}{5} \right)(3) = 0.6 \text{ A} \]

Thus, the "apparent resistance" "seen" in the primary is

\[ R_i = \frac{V_1}{I_1} = \frac{120 \text{ V}}{0.6 \text{ A}} = 200 \text{ Ω} \]

Chapter 28

True or false?
1. A "quantum jump" is an extraordinarily large change in some variable (such as energy, for example), much larger than what had typically been seen before. **F.** Energy levels for bound systems (such as an electron bound inside an atom) are quantized; this means that only certain energies are possible. A quantum jump is a transition from one of the allowed energies to another allowed energy.

2. In the photoelectric effect, increasing the intensity of the incident light increases the current flowing in the apparatus. **T.** Increasing the intensity of the incident light increases the
number of photons, but not their energy. Therefore, the number of electrons ejected per unit time (which is the current) will be increased (as long as the frequency of each photon is greater than the threshold frequency), but the maximum kinetic energy of the ejected electrons will not increase.

3 Each metal has a threshold frequency with respect to the photoelectric effect; that is, for incident light with frequency below the threshold frequency, no electrons are ejected from the metal. T. For frequencies below the threshold frequency, the incident photons do not have enough energy; electrons that absorb photons with energy that is too small will not have enough energy to overcome the attractive forces of the metal and escape from the metal.

CP 13 Light with a wavelength of 350 nm shines on a metal surface, which emits electrons. The stopping potential is measured to be 1.25 V. (a) Determine the maximum speed of emitted electrons. (b) Calculate the work function and identify the metal.

\[
K_{\text{max}} = e \cdot V_{\text{stop}} \quad \text{(note the short-cut used)}
\]

(a) \[K_{\text{max}} = 1.25 \text{ eV}\]
\[
\frac{1}{2} m v_{\text{max}}^2 = 1.25 \times 1.6 \times 10^{-19} \text{ J}
\]
\[
v_{\text{max}}^2 = \frac{2(1.25 \times 1.6 \times 10^{-19})}{9.11 \times 10^{-31}}
\]
\[
= 0.439 \times 10^{12}
\]
\[
v_{\text{max}} = 6.6 \times 10^5 \text{ m/s}
\]

(b) \[K_{\text{max}} = \frac{hc}{\lambda} - E_0 \rightarrow E_0 = \frac{hc}{\lambda} - K_{\text{max}}\]
\[
E_0 = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{350 \times 10^{-9}} - 1.25 \text{ eV}
\]
\[
= 5.68 \times 10^{-19} \text{ J} - 1.25 \text{ eV}
\]
In a photoelectric-effect experiment, the maximum kinetic energy of electrons is 2.8 eV. When the wavelength of the incident light is increased by 50%, the maximum kinetic energy of the electrons decreases to 1.1 eV. Determine the (a) work function of the cathode, and (b) the initial wavelength.

\[ h' \max = \frac{hc}{\lambda} - E_0 \]

\[ 2.8 \text{ eV} = \frac{hc}{\lambda} - E_0 \quad (1) \]

\[ 1.1 \text{ eV} = \frac{hc}{1.5 \lambda} - E_0 \rightarrow 1.65 \text{ eV} = \frac{hc}{\lambda} - 1.5E_0 \quad (2) \]

Alternatively:

\[ 2.8 \text{ eV} = \frac{hc}{\lambda} - E_0 \rightarrow h\lambda = 2.8 \text{ eV} - E_0 \]

\[ 1.65 \text{ eV} = \frac{hc}{\lambda} - 1.5E_0 \]

\[ 1.65 \text{ eV} = 2.8 \text{ eV} + E_0 - 1.5E_0 \]

\[ 0.5E_0 = 1.15 \text{ eV} \rightarrow E_0 = 2.3 \text{ eV} \]

\[ (1) - (2) \Rightarrow 1.15 \text{ eV} = 0.5E_0 \]

(a) \[ E_0 = 2.3 \text{ eV} \]

(b) Back to (1):

\[ 2.8 \text{ eV} = \frac{hc}{\lambda} - 2.3 \text{ eV} \]
In a photoelectric-effect experiment, the stopping potential at a wavelength of 400 nm is 25.7% of the stopping potential at a wavelength of 300 nm. Of what metal is the cathode made?

\[ V_{\text{Stop}} = \frac{V_{\text{max}}}{e} = \left( \frac{hc}{\lambda} - E_0 \right) = \frac{1}{e} \left( \frac{hc}{\lambda} - E_0 \right) \]

\[ V_{\text{Stop1}} = 0.257 V_{\text{Stop2}} \]

\[ \frac{1}{e} \left( \frac{hc}{400\text{nm}} - E_0 \right) = (0.257) \left( \frac{1}{e} \right) \left( \frac{hc}{300\text{nm}} - E_0 \right) \]

\[ \frac{hc}{400\text{nm}} - E_0 = 0.257 \left( \frac{hc}{300\text{nm}} - E_0 \right) \]

\[ \frac{hc}{400\text{nm}} - E_0 = 0.257 \frac{hc}{300\text{nm}} - 0.257 E_0 \]

\[ 0.743 E_0 = hc \left( \frac{1}{400\text{nm}} - \frac{0.257}{300\text{nm}} \right) \]

\[ E_0 = \frac{(6.63 \times 10^{-34}) (3 \times 10^8)}{0.743} \left( \frac{1}{400 \times 10^{-9}} - \frac{0.257}{300 \times 10^{-9}} \right) \]

\[ = \frac{(6.63 \times 10^{-34}) (3 \times 10^8)}{0.743} \left( \frac{1}{400} - \frac{0.257}{300} \right) \frac{1}{10^{-9}} \]

\[ = \frac{(6.63 \times 10^{-34}) (3 \times 10^8)}{0.743} \left( \frac{1}{400} - \frac{0.257}{300} \right) 10^9 \]

\[ E_0 = 4.4 \times 10^{-19} \text{ J} \]

\[ = 4.4 \times 10^{-19} \text{ eV} \]

\[ E_0 = 2.75 \text{ eV} \]

Sodium? (maybe) — check table on p927
Chapter 29

True or false?
1. Energy levels of electrons in a hydrogen atom are quantized; this means that their energies cannot be known for certain, because of Heisenberg's uncertainty principle. **F.** The energy levels are quantized, which means that only certain energies are allowed. These allowed energy values can be calculated very precisely using quantum mechanics, and experiments verify the predictions very precisely.
2. The only way for an electron in an atom to make a transition from one energy state to a higher energy state is to absorb a photon of the right amount of energy. **F.** An electron can be bumped by another electron and absorb just enough energy from the collision to induce the transition to the higher energy state.
3. In an oxygen atom, not all of the electrons can be simultaneously in a 1s\(^2\) state; this is a consequence of Pauli's exclusion principle. **T.** According to Pauli's exclusion principle, no two fermions (and electrons are fermions) can have the same set of quantum numbers. Only two different sets of quantum numbers are possible for electrons in the 1s\(^2\) state, so the maximum number of electrons that can be in this state is 2.

CP 44. A 2.55 eV photon is emitted from a hydrogen atom. Determine the Balmer formula \(n\) and \(m\) values corresponding to this emission.

\[
E_n = -\frac{13.6}{n^2}
\]

By inspection, the transition is from

\[
\begin{align*}
E_n &= -0.85 \text{ eV} & n &= 4 \\
&= -1.51 \text{ eV} & n &= 3 \\
&= -3.02 \text{ eV} & m &= 2 \\
&= -13.6 \text{ eV} & n &= 1
\end{align*}
\]
The first three energy levels of the fictitious element \( X \) are shown in the figure. (a) Determine the wavelengths observed in the absorption spectrum of element \( X \). (b) State whether each of your wavelengths in Part (a) corresponds to ultraviolet light, visible light, or infrared light. (c) An electron with a speed of \( 1.4 \times 10^6 \text{ m/s} \) collides with an atom of element \( X \). Shortly afterward, the atom emits a 1240 nm photon. What was the electron's speed after the collision? Assume that, because the atom is so much more massive than the electron, the recoil of the atom is negligible.

(a) Absorption spectrum:

<table>
<thead>
<tr>
<th>( n )</th>
<th>Energy Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-6.5 eV</td>
</tr>
<tr>
<td>2</td>
<td>-3.0 eV</td>
</tr>
<tr>
<td>3</td>
<td>-2.0 eV</td>
</tr>
</tbody>
</table>

The corresponding wavelengths are:

\[
\frac{hc}{\lambda} = 3.5 \text{ eV} \quad \text{and} \quad \frac{hc}{\lambda} = 4.5 \text{ eV}
\]

\[
\lambda = \left( \frac{6.63 \times 10^{-34}}{3 \times 10^8} \right) \left( \frac{3 \times 10^8}{3.5 \times 1.6 \times 10^{-19}} \right) = 3.55 \times 10^{-7} \text{m} \quad \text{and} \quad \lambda = \left( \frac{6.63 \times 10^{-34}}{4.5 \times 1.6 \times 10^{-19}} \right) = 2.76 \times 10^{-7} \text{m}
\]

\( \lambda = 355 \text{ nm} \quad \text{and} \quad \lambda = 2.76 \text{ nm} \)

Both wavelengths are in the ultraviolet part of the spectrum.

(c) Determine the energy of the emitted photon:

\[
E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(1240 \times 10^{-9})(1.6 \times 10^{-19})} \text{ eV} = 1.003 \text{ eV}
\]

\( \text{Be careful here.} \)
A fictitious atom has only two absorption lines in its spectrum, at 250 nm and 600 nm. What is the wavelength of the one line in the emission spectrum that does not appear in the absorption spectrum?

Determine the energy differences for each transition:

\[ \Delta E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(250 \times 10^{-9})(1.6 \times 10^{-19})} \text{ eV} = 4.97 \text{ eV} \]

\[ \Delta E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(600 \times 10^{-9})(1.6 \times 10^{-19})} \text{ eV} = 2.07 \text{ eV} \]

Thus, the energy level diagram looks like (with an arbitrary choice of 0 for the ground state):

The wavelengths in the absorption spectrum correspond to 4.97 eV and 2.07 eV.
absorption spectrum correspond to transitions \( n=1 \) to \( n=2 \) and \( n=1 \) to \( n=3 \). The same wavelengths are found in the emission spectrum, corresponding to the transitions \( n=2 \) to \( n=1 \) and \( n=3 \) to \( n=1 \), but there is also a wavelength corresponding to the transition \( n=3 \) to \( n=2 \):

\[
(4.97 - 2.07) \text{ eV} = \frac{hc}{\lambda}
\]

\[
\lambda = \frac{hc}{2.90 \text{ eV}}
\]

\[
= \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(2.90)(1.6 \times 10^{-19})}
\]

\[
= 4.3 \times 10^{-7} \text{ m}
\]

\( \lambda = 430 \text{ nm} \)