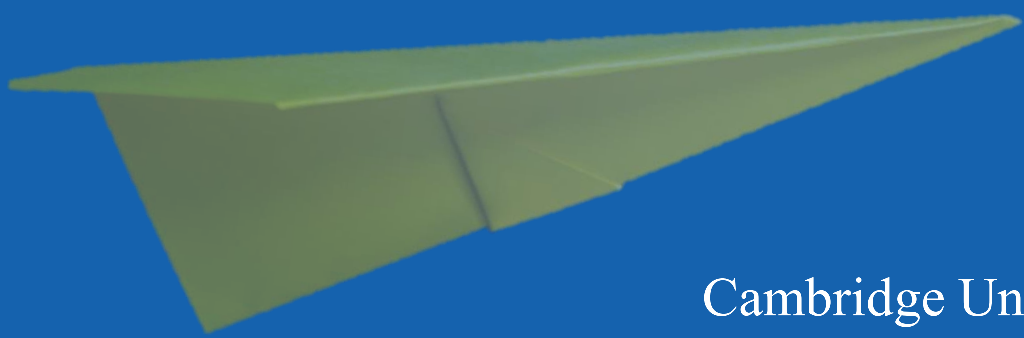
Clicker Questions

Modern Physics

by Gary Felder and Kenny Felder



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Instructions

- These questions are offered in two formats: a deck of PowerPoint slides, and a PDF file. The two files contain identical contents. There are similar files for each of the 14 chapters in the book, for a total of 28 files.
- Each question is marked as a “Quick Check” or “ConcepTest.”
  - Quick Checks are questions that most students should be able to answer correctly if they have done the reading or followed the lecture. You can use them to make sure students are where you think they are before you move on.
  - ConcepTests (a term coined by Eric Mazur) are intended to stimulate debate, so you don’t want to prep the class too explicitly before asking them. Ideally you want between 30% and 80% of the class to answer correctly.
- Either way, if a strong majority answers correctly, you can briefly discuss the answer and move on. If many students do not answer correctly, consider having them talk briefly in pairs or small groups and then vote again. You may be surprised at how much a minute of unguided discussion improves the hit rate.
- Each question is shown on two slides: the first shows only the question, and the second adds the correct answer.
- Some of these questions are also included in the book under “Conceptual Questions and ConcepTests,” but this file contains additional questions that are not in the book.
- Some of the pages contain multiple questions with the same set of options. These questions are numbered as separate questions on the page.
- Some questions can have multiple answers. (These are all clearly marked with the phrase “Choose all that apply.”) If you are using a clicker system that doesn’t allow multiple responses, you can ask each part separately as a yes-or-no question.

11 Solids

11.1 Crystals

Which crystal type is NaCl? (Choose one.)

A. simple cubic

B. fcc

C. bcc

D. other

Which crystal type is NaCl? (Choose one.)

A. simple cubic

B. fcc

C. bcc

D. other

Solution: B

For each of the following, does it A) contribute positively to the cohesive energy, B) contribute negatively to the cohesive energy, or C) not contribute to the cohesive energy?

1. The electric attraction between oppositely charged ions
2. The electric repulsion between ions of the same charge
3. the electric repulsion between partially unshielded nuclei
4. Pauli repulsion

For each of the following, does it A) contribute positively to the cohesive energy, B) contribute negatively to the cohesive energy, or C) not contribute to the cohesive energy?

1. The electric attraction between oppositely charged ions

   Solution: negatively

2. The electric repulsion between ions of the same charge

   Solution: positively

3. the electric repulsion between partially unshielded nuclei

   Solution: positively

4. Pauli repulsion

   Solution: positively

In ice, hydrogens are bonded to oxygens covalently and the resulting charge imbalance causes the oxygens to be attracted to the hydrogens that they aren't covalently bonded with. That all makes ice . . . (Choose one.)

A. an ionic crystal

B. a covalent solid

C. a metal

D. a molecular solid

In ice, hydrogens are bonded to oxygens covalently and the resulting charge imbalance causes the oxygens to be attracted to the hydrogens that they aren't covalently bonded with. That all makes ice . . . (Choose one.)

A. an ionic crystal

B. a covalent solid

C. a metal

D. a molecular solid

Solution: D

How many atoms are in a unit cell of CsCl (Figure 11.4 on p. 506)? (Choose one.)

A. 2

B. 9

C. 16

D. 18

E. 28

How many atoms are in a unit cell of CsCl (Figure 11.4 on p. 506)? (Choose one.)

A. 2

B. 9

C. 16

D. 18

E. 28

Solution: 16. If you wanted to build this structure you would need to start with eight cesium ions arranged in a simple cube, and eight chlorine ions also arranged in a cube, but offset diagonally so that one chlorine ion was right in the center of the cesium cube. Once you have that, you can just repeat it ad infinitum in every direction.

11.2 Band Structure and Conduction

Suppose a particular metal has an "allowable energy band" between 3 eV and 4 eV. Which of the following best describes what that means? (Choose one.)

A. An electron will never be measured with any energy between 3 and 4 eV.

B. There is exactly one allowed energy level between 3 and 4 eV.

C. The allowed energy levels between 3 and 4 eV are evenly spaced, such as (for instance) occurring every 1/10 eV throughout that region.

D. There are so many energy levels between 3 and 4 eV, so closely spaced, that an electron can have virtually any energy in that range.

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D. There are so many energy levels between 3 and 4 eV, so closely spaced, that an electron can have virtually any energy in that range.

Solution: D

We typically describe the ions in a crystal lattice as being perfectly evenly spaced: in other words, periodic. But in fact, their random thermal vibrations break that perfect symmetry. Why, in the context of this section, is that symmetry-breaking important? (Choose one.)

A. If the lattice were perfectly periodic, an applied voltage would increase current indefinitely.

B. If the lattice were perfectly periodic, no current could flow.

C. If the lattice were perfectly periodic, the energy levels would not be organized into bands.

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A. If the lattice were perfectly periodic, an applied voltage would increase current indefinitely.

B. If the lattice were perfectly periodic, no current could flow.

C. If the lattice were perfectly periodic, the energy levels would not be organized into bands.

Solution: A

You apply an electric field to a conductor and current starts to flow. You apply the same field to an insulator and no current starts to flow. What structural difference leads to this behavioral difference? (Choose one.)

A. The energy levels in the conductor are organized into bands; the levels in the insulator are not.

B. Both of them have energy levels organized into bands, but the gap between bands is bigger in the insulator.

C. The highest-level electrons in the conductor can be kicked up into a slightly higher energy level; the highest-level electrons in the insulator cannot.

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B. Both of them have energy levels organized into bands, but the gap between bands is bigger in the insulator.

C. The highest-level electrons in the conductor can be kicked up into a slightly higher energy level; the highest-level electrons in the insulator cannot.

Solution: C

Which of the following best describes the electrons that conduct current in a wire when an external potential is applied? (Choose one.)

A. They are all moving at constant velocity.

B. They are all moving at constant acceleration.

C. They are alternately accelerating and colliding with obstacles.

D. They are all moving in different directions, with no net average velocity.

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B. They are all moving at constant acceleration.

C. They are alternately accelerating and colliding with obstacles.

D. They are all moving in different directions, with no net average velocity.

Solution: C

11.3 Semiconductors and Diodes

An n-type extrinsic semiconductor has which of the following? (Choose one.)

A. A significant number of electrons in the conduction band

B. A significant number of holes in the valence band

C. Both A and B

D. Neither A nor B

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Solution: A

Look at a periodic table such as Appendix H. Would germanium doped with gallium be . . . (Choose one.)

A. n-type?

B. p-type?

C. neither?

Look at a periodic table such as Appendix H. Would germanium doped with gallium be . . . (Choose one.)

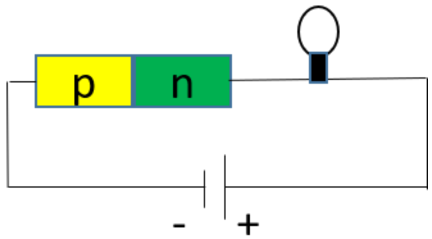
A. n-type?

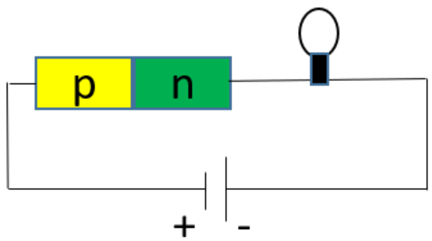
B. p-type?

C. neither?

Solution: B

In which of the following circuits would the light bulb be seen to glow? (Choose one.)

A. 

B. 

C. Both A and B

D. Neither A nor B

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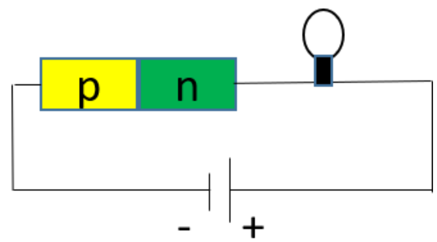
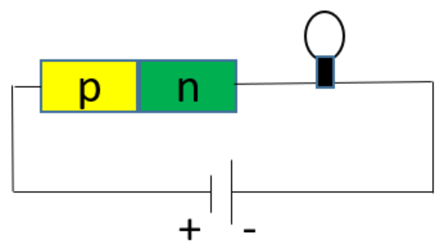
A. 

B. 

C. Both A and B

D. Neither A nor B

Solution: B

Figure 11.16 on p. 519 shows a p-n junction in equilibrium. Which side has a higher electric potential, the p-side or the n-side?

Hint: Remember that electrons are negatively charged.

Figure 11.16 on p. 519 shows a p-n junction in equilibrium. Which side has a higher electric potential, the p-side or the n-side?

Hint: Remember that electrons are negatively charged.

Solution: Electrons have migrated from the n-side to the p-side. If you were a (semi-mythical) ambulatory positive charge you would want to follow them, moving from the n-side to the p-side, so the n-side has the higher potential.

Are you wondering why the drawing looks the other way? Because the drawing represents the potential *energy* of the various levels an electron can inhabit. An electron in a region of low potential has a high potential energy, and vice versa.

At what energy is the Fermi energy in an n-type semiconductor? (Choose one.)

A. Near the top of the valence band

B. Near the middle of the band gap

C. Near the bottom of the conduction band

D. None of the above

At what energy is the Fermi energy in an n-type semiconductor? (Choose one.)

A. Near the top of the valence band

B. Near the middle of the band gap

C. Near the bottom of the conduction band

D. None of the above

Solution: C. Remember that the Fermi energy is between the highest-level energy where you *do* find electrons (when the system is in its ground state), and the lowest-level energy where you *don't*. An n-type semiconductor in its ground state has electrons at the bottom of the conduction band, but there's still plenty of unfilled states there, so the Fermi energy is at the bottom of the conduction band.

11.4 Transistors

Below are descriptions of five different circuit elements. For each one, choose one of the following:

A. Battery

B. Resistor

C. Diode

D. Transistor

1. Allows current to flow in one direction, but not in the other.
2. Has a voltage drop across it if current is flowing through it, and not otherwise.
3. An applied voltage at one lead controls the flow of current between two different leads.
4. Maintains a constant voltage

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A. Battery

B. Resistor

C. Diode

D. Transistor

1. Allows current to flow in one direction, but not in the other.

   Solution: C

2. Has a voltage drop across it if current is flowing through it, and not otherwise.

   Solution: B

3. An applied voltage at one lead controls the flow of current between two different leads.

   Solution: D

4. Maintains a constant voltage

   Solution: A

Which of the following best describes the effect of a reverse-biased voltage applied at the gate of a field effect transistor? (Choose one.)

A. It pushes electrons from the n-type semiconductor to the p-type semiconductor.

B. It pushes electrons from the p-type semiconductor to the n-type semiconductor.

C. It expands the depletion region between the two semiconductors.

D. It reduces the depletion region between the two semiconductors.

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C. It expands the depletion region between the two semiconductors.

D. It reduces the depletion region between the two semiconductors.

Solution: C

An OR gate has two input leads and one output lead. Which of the following settings of the two input leads would cause the output lead to read high? (Choose all that apply.)

A. High-High

B. High-Low

C. Low-High

D. Low-Low

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A. High-High

B. High-Low

C. Low-High

D. Low-Low

Solution: A, B, C

11.5 Why Do Crystals Have a Band Structure?

The width of an energy band is determined by . . . (Choose one.)

A. the lattice spacing.

B. the number of atoms in the lattice.

C. both.

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A. the lattice spacing.

B. the number of atoms in the lattice.

C. both.

Solution: A

The number of states in each energy band is mostly determined by . . . (Choose one.)

A. the lattice spacing.

B. the number of atoms in the lattice.

The number of states in each energy band is mostly determined by . . . (Choose one.)

A. the lattice spacing.

B. the number of atoms in the lattice.

Solution: B

An electron in an infinite periodic lattice can have …(Choose one.)

A. any values of k or E.

B. any value of k but only certain values of E.

C. any value of E but only certain values of k.

D. only certain values of k and of E.

An electron in an infinite periodic lattice can have …(Choose one.)

A. any values of k or E.

B. any value of k but only certain values of E.

C. any value of E but only certain values of k.

D. only certain values of k and of E.

Solution: B

True or false? Each energy band in a lattice is associated with a subshell of the individual atom’s eigenstates.

True or false? Each energy band in a lattice is associated with a subshell of the individual atom's eigenstates.

Solution: False

If two crystals are made of different types of atoms, but both have the same lattice spacing, will they have the same band structure?

If two crystals are made of different types of atoms, but both have the same lattice spacing, will they have the same band structure?

Solution: The band structure would be different. You can see that from either argument presented in this section, but let's take the bringing-atoms-together argument. The energy levels from the original atoms expand and merge into the bands, and those original energy levels are very different for different types of atoms.

In the text we made arguments for why we would expect allowed and forbidden bands of energy for an electron in a periodic potential. In which situations would those arguments hold? (Choose one.)

A. The total energy is lower than the top of the potential barrier (so classically the particle would be trapped in a single well).

B. The total energy is higher than the top of the potential barrier (so classically the particle would be able to propagate freely).

C. It applies in both of these scenarios.

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C. It applies in both of these scenarios.

Solution: C. Nothing in our argument depended on whether the energy was above or below the barriers. In either case there will be a transmitted and a reflected wave from each barrier, and when you sum up the reflected waves from all the barriers the result will be small except for values of k that meet the resonance condition.

You might think that the electron energy would have to be lower than the barrier height since the electron is bound inside the solid, but that binding results from boundary effects at the edge of the solid. In the interior you can have tightly bound electrons and electrons that can move freely throughout the lattice.

11.6 Magnetic Materials

A solid whose atoms have all their subshells filled is …(Choose one.)

A. A diamagnet

B. A paramagnet

C. A ferromagnet

D. It could be any of these.

A solid whose atoms have all their subshells filled is . . . (Choose one.)

A. A diamagnet

B. A paramagnet

C. A ferromagnet

D. It could be any of these.

Solution: A

The magnetic susceptibility of a paramagnet is . . . (Choose one.)

A. Positive

B. 0

C. Negative

The magnetic susceptibility of a paramagnet is . . . (Choose one.)

A. Positive

B. 0

C. Negative

Solution: A

Copper is classified as diamagnetic, aluminum paramagnetic. If you put a block of copper and a block of aluminum in an upward-pointing magnetic field, what will happen? (Choose one.)

A. They will both create internal magnetic fields pointing upward.
B. They will both create internal magnetic fields pointing downward.
C. The copper will create an internal magnetic field pointing upward, the aluminum downward.
D. The copper will create an internal magnetic field pointing downward, the aluminum upward.

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B. They will both create internal magnetic fields pointing downward.

C. The copper will create an internal magnetic field pointing upward, the aluminum downward.

D. The copper will create an internal magnetic field pointing downward, the aluminum upward.

Solution: D

Copper is classified as diamagnetic, aluminum paramagnetic. If you peek at how they react to an applied magnetic field at the atomic level, what will you see? (Choose one.)

A. Copper atoms show the diamagnetic effect but not the paramagnetic effect. Aluminum atoms show the paramagnetic effect but not the diamagnetic effect.

B. All the atoms show both effects. But in copper the diamagnetic effect is stronger, and in aluminum the paramagnetic effect is stronger.

C. Copper shows the diamagnetic effect only. Aluminum shows both, but the paramagnetic is stronger.

D. Aluminum shows the paramagnetic effect only. Copper shows both, but the diamagnetic is stronger.

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B. All the atoms show both effects. But in copper the diamagnetic effect is stronger, and in aluminum the paramagnetic effect is stronger.

C. Copper shows the diamagnetic effect only. Aluminum shows both, but the paramagnetic is stronger.

D. Aluminum shows the paramagnetic effect only. Copper shows both, but the diamagnetic is stronger.

Solution: C

Curie's law says which of the following? (Choose one.)

A. The induced field of a diamagnet becomes stronger at higher temperatures.

B. The induced field of a diamagnet becomes weaker at higher temperatures.

C. The induced field of a paramagnet becomes stronger at higher temperatures.

D. The induced field of a paramagnet becomes weaker at higher temperatures.

E. Don't spend years working with radioactive materials with no protective gear.

Curie’s law says which of the following? (Choose one.)

A. The induced field of a diamagnet becomes stronger at higher temperatures.

B. The induced field of a diamagnet becomes weaker at higher temperatures.

C. The induced field of a paramagnet becomes stronger at higher temperatures.

D. The induced field of a paramagnet becomes weaker at higher temperatures.

E. Don’t spend years working with radioactive materials with no protective gear.

Solution: D

If you put some solids near a permanent magnet, which will be attracted to the magnet? (Choose one.)

A. A diamagnet

B. A paramagnet

C. Both

D. Neither

If you put some solids near a permanent magnet, which will be attracted to the magnet? (Choose one.)

A. A diamagnet

B. A paramagnet

C. Both

D. Neither

Solution: B. The paramagnet will line up with the field of the magnet. For example, if the North end of the permanent magnet is next to the paramagnet then that side of the paramagnet will be South, and they will attract each other. The diamagnet will have the opposite orientation and be repelled.

Are the noble gases…

A. diamagnetic, or

B. paramagnetic?

Are the noble gases…

A. diamagnetic, or

B. paramagnetic?

Solution: Diamagnetic. What makes these gases so gosh-darned noble is that their outer shells are completely filled, which means all their electrons are paired up, which means they have no overall magnetic moments of their own to respond in a paramagnetic way. Moreover, they don't bond together so there are no molecular or solid bonds to complicate the electron structure.

Inside a block of iron, where is the energy density typically higher:

A. within a domain, or

B. on the boundary between domains?

A. within a domain, or

B. on the boundary between domains?

Solution: B, on the boundary. Within a domain the magnetic moments are all aligned, precisely because that tends to lower the energy.

A superconductor completely repels external magnetic fields, leading to zero field within the superconductors. What is the magnetic susceptibility of a superconductor? (Choose one.)

A. $\chi < -1$

B. $\chi = -1$

C. $-1 < \chi < 0$

D. $\chi = 0$

E. $0 < \chi < 1$

F. $\chi = 1$

G. $\chi > 1$

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E. $0 < \chi < 1$

F. $\chi = 1$

G. $\chi > 1$

Solution: B. In order to cancel out an external magnetic field $\vec{B}$ the superconductor has to set up an internal field $-\vec{B}$.

11.7 Heat Capacity

The law of Dulong and Petit says that at room temperature most solids have . . . (Choose all that apply.)

A. the same total heat capacity.

B. the same heat capacity per unit atom.

C. the same heat capacity per unit mass.

The law of Dulong and Petit says that at room temperature most solids have ... (Choose all that apply.)

A. the same total heat capacity.

B. the same heat capacity per unit atom.

C. the same heat capacity per unit mass.

Solution: B

The primary difference between the Dulong and Petit model and the Einstein model is… (Choose one.)

A. The first model treats atomic oscillations classically, while Einstein's model treats them quantum mechanically.

B. The first model treats every atomic oscillation as independent of every other, while Einstein's model treats them as an interrelated system.

C. The first model considers only the nuclei, while Einstein's model also factors in the electrons.

D. The first model treats time, space, and velocity classically, while Einstein's model is relativistic.

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C. The first model considers only the nuclei, while Einstein's model also factors in the electrons.

D. The first model treats time, space, and velocity classically, while Einstein's model is relativistic.

Solution: A

Einstein's model generally improves upon the law of Dulong and Petit...(Choose all that apply.)

A. At very low temperatures.

B. At room temperatures.

C. At very high temperatures.

Einstein's model generally improves upon the law of Dulong and Petit. . . (Choose all that apply.)

A. At very low temperatures.

B. At room temperatures.

C. At very high temperatures.

Solution: A

The primary difference between Einstein's model and Debye's model is. . . (Choose one.)

A. Einstein's model treats atomic oscillations classically, while Debye's model treats them quantum mechanically.

B. Einstein's model treats every atomic oscillation as independent of every other, while Debye's model treats them as an interrelated system.

C. Einstein's model considers only the nuclei, while Debye's model also factors in the electrons.

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C. Einstein's model considers only the nuclei, while Debye's model also factors in the electrons.

D. Einstein's model treats time, space, and velocity classically, while Debye's model is relativistic.

Solution: B

For most solids, the partial derivative $\partial C/\partial T$ is . . . (Choose one.)

A. negative.

B. zero.

C. positive.

D. It depends on the temperature.

For most solids, the partial derivative $\partial C/\partial T$ is . . . (Choose one.)

A. negative.

B. zero.

C. positive.

D. It depends on the temperature.

Solution: C

At room temperature diamond has a much lower specific heat capacity than the law of Dulong and Petit predicts. That implies… (Choose one.)

A. Diamond has a low Debye temperature.

B. Diamond has a high Debye temperature.

C. Diamond is not well described by the Debye model.

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A. Diamond has a low Debye temperature.

B. Diamond has a high Debye temperature.

C. Diamond is not well described by the Debye model.

Solution: B

Recall that specific heat capacity is an increasing function of T/T_D. So, consider a diamond and a piece of iron, both at room temperature. If the diamond has a much lower c then it must have a much lower T/T_D, which means it must have a much higher T_D. Put another way, T_D is a rough estimate of the temperature above which the law of Dulong and Petit approximately holds, so having a lower c than the law of Dulong and Petit predicts means diamond at room temperature is still much colder than its Debye temperature. (It means the same thing about its Einstein temperature T_E.)

One key feature of the Debye model is that the sum over all the oscillations cuts off at a maximum frequency. Is that cutoff more important at…

A. high temperatures, or

B. low temperatures?

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A. high temperatures, or

B. low temperatures?

Solution: The cutoff matters at high temperatures. Here's why.

According to the Debye model, each standing wave can have energy 0, $\hbar\omega$, $2\hbar\omega$, and so on, where ω takes on different values for the different standing waves. (We're still ignoring the ground state energies.)

At low temperatures the high-frequency waves don't have enough thermal energy to reach their first excited states, so they are essentially all frozen out in their ground states. For purposes of heat capacity, therefore, those waves don't matter. Hence the frequency cutoff is irrelevant at low temperatures; it becomes important when there is enough energy that you *could* excite those higher-frequency waves if they existed, which they don't. More specifically, the cutoff begins to matter when $k_B T$ is comparable to the first excited state of the highest (cutoff) frequency.

Here's another interesting point about that cutoff. Recall that we said that the math of the Debye model is very similar to that of cavity radiation, except that the Debye model has a high frequency cutoff because of the lattice spacing. That means that at high temperatures the energy in cavity radiation grows much faster (proportional to T^4) than the energy of a lattice (proportional to T). At higher temperatures you unfreeze more and more modes in a cavity, while in a lattice you just linearly add more energy to the modes that are already unfrozen.

The spectroscopic notation for an aluminum atom is $1s^2 2s^2 2p^6 3s^2 3p^1$. Which of the following dominates the heat capacity of aluminum at temperatures very close to absolute zero? (Choose one.)

A. The protons and neutrons in the nucleus.

B. The two electrons in the 1s shell.

C. The electron in the 3p shell.

D. All of the electrons contribute significantly.

E. All of the electrons and the nuclei contribute significantly.

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B. The two electrons in the 1s shell.

C. The electron in the 3p shell.

D. All of the electrons contribute significantly.

E. All of the electrons and the nuclei contribute significantly.

Solution: C. The electron in the 3p shell is the only one that can get excited, so it is the one whose energy might change with a change in temperature.

At temperatures very close to absolute zero, what effect would you expect n-doping a semiconductor to have on its heat capacity? (Choose one.)

A. Increase it

B. Decrease it

C. Not change it

At temperatures very close to absolute zero, what effect would you expect n-doping a semiconductor to have on its heat capacity? (Choose one.)

A. Increase it

B. Decrease it

C. Not change it

Solution: A. In its intrinsic state the semiconductor does not have any electrons that can be excited (unless they get *really* excited, which isn't going to happen at these low temperatures). But throw in a bit of n-doping and you have electrons sitting at the bottom of the conduction band, ready to accept any energy—even very small amounts of energy—that you throw at them.