# AP Physics – Heat Flow, Specific Heat, and Latent Heat

***Heat Transfer by Conduction:*** Materials that allow heat to flow through them easily are called ***heat conductors***, materials which do not allow heat to flow through them are called ***heat insulators***.

Heat conductors are things like metals. Metals are good conductors because of the nature of the chemical bond that binds the atoms together. These bonds are called ***metallic bonds***. The significant thing about the bonds are that some of the electrons of each atom are not bound to any one particular atom – they’re kind of like “community” electrons belonging to everyone. They are very loosely held and can move around throughout the metal. These are known as ***free electrons***. The free electrons carry the heat from one part of the metal to another. They do this via collisions wherein one electron gives some of its energy to another. This can happen very quickly so that the heat transfers quite easily.

Insulators do not have handy little particles that can collide with each other transferring energy from one place to another. There are no free electrons to do this. If it is a solid, then the electrons are going to be tightly held via covalent or ionic bonds.

Gases make very good insulators because there aren’t many particles to carry the energy from one place to another.

Clearly a vacuum would be even better!

Most insulators are actually materials that have lots of little pockets of air (or a fancy gas) in them. The gas slows the flow of heat way down.

Thermos bottles are very interesting. You can put a hot fluid in the thing and it will stay hot or you can put a cold fluid in it and the fluid will stay cold. The question is this, “How does the bottle know what to do?” Maybe a microchip thingee? Hmmm. Well, actually, thermos bottles are very simple devices. The have an external metal or plastic body, inside of this body is a glass bottle. Really good thermos bottles have a vacuum between the outer case and glass bottle. The glass bottle is mirrored. Heat is kept from flowing by the vacuum which prevents conduction and convection. The mirror surface prevents heat flow by radiation – the mirror reflects the electromagnetic waves (infrared waves, right?). So thermos bottles do a pretty good job of blocking the flow of heat coming either into or out of the bottle. So it can keep hot things hot and cold things cold – without microprocessors.

Let us look at a slab of material. One side of the material is at a high temperature and the other side is exposed to a low temperature. Because of the temperature difference, heat will flow through the slab.



The rate at which heat is transferred through an object is proportional to the amount of heat that travels through the object divided by the time:



Where ***H*** is the heat flow rate, ***Q*** is the quantity of heat transferred, and ***t*** is the time.

The amount of heat that makes it through depends on thickness of the substance, the area of the object, and the thermal properties of the material. The thermal properties are expressed in what is called the ***thermal conductivity*** of the substance. Each material has its own value for its thermal conductivity. This thermal conductivity is a measure of the ability of a substance to transfer heat. The symbol for thermal conductivity is ***k***. Materials that have a large value for ***k*** are good heat conductors, materials with low ***k*** values make good insulators.

The heat flow rate for the slab is given by this equation: 

Where ***H*** is the heat flow rate, ***k*** is the thermal conductivity, ***A*** is the area, **Δ*T*** is the temperature difference, and ***L*** is the thickness of the material.

***H*** will have units of J/s, J/min, Cal/h, &tc.

Since  and , Then *Q = H t* so, substituting in for *H*, we get:



This would give us the amount of heat flow that would occur in a given time.

So what can we see from this equation?

Well, the heat is directly proportional to the temperature difference and the area. It is indirectly proportional to the thickness of the slab.

Double the area, double the heat flow. Double the temperature difference, double the heat flow. &tc.

However if you double the thickness, the heat flow decreases by two so it is only one half of what it was before.

*k* can have many different units. Two common units are  or 

Generally one looks up the required *k* values. One could also work them out experimentally.

|  |  |
| --- | --- |
| Thermal Conductivities | J/s⋅m⋅°C |
| Aluminum | 238 |
| Copper | 397 |
| Gold | 314 |
| Iron | 79.5 |
| Lead | 34.7 |
| Silver | 427 |
| Air | 0.0234 |
| Fiberglass | 0.042 |
| Hydrogen | 0.172 |
| Drywall | 0.16 |
| Brick | 0.71 |
| Asbestos | 0.25 |
| Concrete | 1.3 |
| Glass | 0.84 |
| Cork | 0.042 |
| Rubber | 0.2 |
| Water | 0.60 |
| Wood | 0.10 |

***Mechanical equivalent of heat:*** One of the great discoveries in physics in the 1800’s was made by James Joule who discovered that heat and mechanical energy were equivalent.

One of the units used to measure heat was the calorie. A calorie is the amount of heat it takes to raise the temperature of one cubic centimeter of water by one degree Celsius. Joule found that heat could be related to mechanical energy.

Here is a description of Joule’s elegant experiment. An insulated container was filled with water. The temperature of the water could be monitored with a thermometer. In the water tank was a set of paddles that could rotate. A piece of line was attached to the paddles and run over a pulley system. A weight was attached to the line and released. The weight would fall down, causing the paddle to rotate in the water, thus doing work. The temperature of the water increased, indicating that heat had entered the system, even though it was insulated. Joule found that the amount of work done by the weight was equal to the thermal energy that increased the water’s temperature.

The relationship between the calorie and the joule is:



You’ve heard of calories long before you took chemistry. In these health conscious days, the amount of energy in the food, measured in Calories, is of great concern.

What’s kind of weird is that food calories are different than regular heat calories. Food Calories begin with a capital C and are actually one thousand calories.

1 Cal = 1 kcal

* A serving of fried frog legs provides 876 Cal per serving. If you eat two servings, (a) how many joules of mechanical work must you do to “burn off” the frog leg calories? (b) If you climbed a staircase to work off the frog legs, how high would you have to climb? You have a mass of 58 kg.

That’s a lot of stair climbin’.

***Heat and Temperature Change:*** The heat required to raise the temperature of a substance can be looked at in several ways. The way we look at it in physics is to use a thing called the specific heat.

***Specific Heat ≡ heat to raise the temperature of one gram of a substance by one degree Celsius.***

The specific heat can be found experimentally, but usually you just look it up in a table. This elegant document has just such a table – the very thing!

The heat required to raise a substance’s temperature is given by this equation:



***Q*** is the heat, ***m*** is the mass of the substance, ***c*** is the specific heat, and ***ΔT*** is the temperature difference.

* 34 000 J of heat is added to a 2.5 kg sample of water. What is the temperature change that takes place?

***Law of Heat Exchange:*** When two systems are in thermal contact, heat will flow between them until they reach thermal equilibrium at some equilibrium temperature. The systems will obey the law of heat exchange.

***Law of Heat Exchange ≡ The heat lost by the hot system is equal to the heat gained by the cold system***.

This means that: ***QLost = QGained***

* A 235 g gold ball at a temperature of 125°C is dropped into an insulated flask of water. The water was initially at a temperature of 22°C. If the equilibrium temperature is 25°C, what is the mass of the water?

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Table of Specific Heat Values For Common Substances

|  |  |
| --- | --- |
| Substance | J/kg °C |
| Aluminum | 909 |
| Beryllium | 182 |
| Cadmium | 230.0 |
| Brass | 384 |
| Copper | 387 |
| Germanium | 322 |
| Glass | 837 |
| Gold | 129 |
| Water | 4186 |
| Ice | 2090 |
| Steam | 201 |
| Iron | 448 |
| Lead | 128 |
| Mercury | 138 |
| Silicon | 703 |
| Brass | 384 |
| Silver | 234 |

1. A 158.0 g brass ball at a temperature of 265 °C is dropped into a container containing 550.0 g of water. If the final temperature of the ball is 35.5 °C, what was the initial temperature of the water?

***Phase changes:*** Phase changes are when a substance goes form one state to another. The states we worry about are: solid, liquid, and gas. So a phase change involves a substance going from one state to another. In physics we are mainly concerned with the energy requirements of the phase change.

Here are the major phase changes:

Melting → Solid becomes a liquid

Solidification (freezing) → Liquid becomes a solid

Vaporization → Liquid becomes a gas

Condensation → Gas becomes a liquid

Sublimation → Solid becomes a gas

Deposition → Gas becomes a solid

Normally when we add heat to a substance its temperature increases. This is what we expect to happen. Heat that does this is called ***sensible heat***. Think of such heat as making sense – you expect heat to change the temperature of a thing.

When a substance changes phase, heat is involved. Some phase changes require heat – you have to add heat to make it happen. These changes are said to be ***endothermic***. Vaporization and melting are endothermic and require the addition of heat.

***Exothermic*** phase changes give off heat. Freezing and condensation are exothermic.

When a substance is changing state, its temperature remains constant. Heat is being added or is leaving, but the heat doesn’t affect the temperature, instead it is involved in either breaking or forming bonds.

Heat added to cause a phase change is called ***latent heat*** (latent meaning hidden).

The heat needed to cause vaporization is called the ***latent heat of*** ***vaporization***. Usually this is shortened to just “heat of vaporization”. It works for both vaporization and condensation. When the substance condenses after being vaporized, it gives off this heat.

The heat involved in melting or freezing is called the ***latent heat of fusion***. Shortened to “heat of fusion”.

The heat required for a phase change of a substance is given by this equation:



***Q*** is heat, ***m*** is mass, and ***L*** is the latent heat for the phase change.

The latent heat of vaporization has this symbol: ***Lv***

The latent heat of fusion has this symbol: ***Lf***

Here’s a handy table of values:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Substance | Melting Point  °C | Heat of Fusion  kJ/kg | Boiling Point  °C | Heat of Vaporization  kJ/kg |
| Helium | - 269.65 | 5.23 | -268.93 | 20.9 |
| Nitrogen | - 209.97 | 25.5 | -195.81 | 201 |
| Oxygen | -218.79 | 13.8 | 182.97 | 213 |
| Ethyl Alcohol | -114 | 104 | 78 | 854 |
| Ammonia | -75 | 452 | 2 870 | 1 370 |
| Water | 0.00 | 333 | 100.00 | 2 256 |
| Sulfur | 119 | 38.1 | 444.6 | 326 |
| Lead | 327.3 | 24.5 | 1750 | 870 |
| Aluminum | 660 | 397 | 2450 | 11 400 |
| Silver | 960.80 | 88.2 | 2193 | 2 330 |
| Gold | 1063.0 | 64.4 | 2660 | 1 580 |
| Copper | 1083.0 | 134 | 1187 | 473 |
| Mercury | -38.87 | 11.8 | 356.58 | 296 |
| Tin | 232 | 60.3 | 2270 | 2 200 |
| Tungsten | 3410 | 180 | 5927 | 824 kj/mole |
| Iron | 1535 | 33.0 | 3000.0 | 6 700 |
| Zinc | 419.4 | 96.3 | 907 | 199 |

***Heat/Temperature Curves:*** When a graph is made up temperature vs heat, the curve will look like the generic one below.

The slopes represent the specific heat of the different phases.

The flat parts of the graph where the temperature does not increase with added heat represent the phase changes. The heat added is latent heat.

Where the graph has a slope, the temperature does increase with energy, so the heat added is sensible heat.

One can find the value of the boiling and melting temperatures by finding the flat areas where the phase changes.

* How much heat is required to melt 2.85 kg of ice at zero degrees Celsius?

Dear Doctor Science,

**If I were to open my freezer door, and then the door to my hot 450 degree oven simultaneously, would not the warm and cold fronts converge in my kitchen, creating miniature tornadoes on the linoleum floor?**

-- David from River Hills, WI

Dr. Science responds:

Indeed, this is how most weather forecasters amuse themselves, when they're not playing "guess the barometric pressure" or "pin the tail on the correct cloud formation." It's best to sweep the kitchen floor before you unloose hundreds of miniature tornadoes, because dust and crumbs accelerated to hundreds of miles an hour can punch a hole in your cabinets. It's a good way to terrorize roaches or ants that have previously walked with impunity on your kitchen floor. Suddenly they're playing Wizard of Oz and chirping "there's no place like home."

Dear Dr. Science,

**Many people realize they can tell the temperature by counting the chirps a cricket makes. But how does the cricket know what temperature it is?**

------ Brian W., Laramie, Wyoming

Dr. Science responds:

Brian, while you're out on the veranda swatting mosquitoes and complaining to your friends about how hot it is, the cricket sits in air-conditioned comfort watching the evening news. Out of boredom, perhaps, or a genuine need to give us information, the cricket communicates this weather data to you. The cricket will also click out (in Morse code) the final sports scores, national headlines and such phrases as "Now this", "Coming up at 11," or "Our White House Correspondent filed this report." Some scientists call the cricket the Ted Koppel of the insect world, which is accurate but somewhat silly. After all, you'll never see Ted Koppel rubbing his legs together. At least I hope you won't.

Dear Doctor Science,

At home we play this little game of placing an ice cube on a smooth table and then shaking some salt on top of it. After a about 30 seconds the ice is stuck to the table. It sometimes requires a lot of force to dislodge it. Why does this happen?

--- john lutz from Seattle, WA

Dr. Science responds:

*I share your queer idea of fun. My lab assistant and I used to sprinkle salt on slugs, until someone reported us for mollusk abuse, and we were forced to take sensitivity training so mind numbing it almost cost me my sanity. In your little game, the ice sticks to the table because salt is a natural aphrodisiac, causing the ice to mate with the table. Yes, salty water is randy water, which is why the sea is so often used as a symbol of romance. People sigh when they look out at the sea, and*

often feel a lump in their, uh, throat and an ache in their heart, both of which are often signs of ozone poisoning, caused by temperature inversions trapping smog along the shoreline, but you probably knew that already.

Dear Doctor Science,

The defroster in my car doesn't work very well and I'm often forced to scrape the frost off the inside of my windshield while I'm driving. Why is there always more frost directly in front of me than in any other area of the windshield?

-- Brian Price from Norfolk, VA

Dr. Science responds:

Your car is trying to kill you. If I were you, I'd trade it in as soon as possible. This defroster malfunction is only the tip of the iceberg, so to speak. One day the brake pedal will be suspiciously soft, and then when you're heading into a curve you'll find you have no brakes at all. I once heard of a Saab that fried its owner with the driver's seat warmer. By the way, never stick your head through a sun roof, even in jest. Those things can close very quickly, even with no one at the control. Yes, new cars are intelligent, flashy, and unbelievably malevolent.