AP Physics - Thermodynamics

"Oh my dear, I say, I *have* taken you be surprise," Colon said, watching as a myriad of emotions flit across the face of the young woman he held in his brawny arms. "You're the most beautiful woman I have ever seen in my life, but I want you to know that it is not only your beauty that has drawn me to you." He paused, reflecting, and then added, " Lord, I sound such a fool. . . . to think that you, such a ravishing creature, might consider a plain, ordinary man like me, and become Lady Falcon's Nest."

Catherine looked up into Colon's deep blue eyes. Her eyelids fluttered and she spoke in a throaty, hesitant voice, "This is so sudden." She shrugged her alabaster shoulders out of Colon's embrace and turned away, paused, and then turned back and stared into those eyes once again, the eyes of Colon, the young Duke of Falcon's Nest. Her heart raced within her bosom. No one had ever spoken to her in such words before. She had always thought of herself as a dull, uninteresting woman. Now, suddenly, to be told such things, and by such a handsome man at that. To become a Lady, and mix with the social elite of the kingdom. Her head was spinning. What did it signify? Did he truly mean what he had said, or, perhaps, was he simply trying to seduce her with sweet words? Catherine had heard of such things.

"Why, yes," Lord Colon continued, "you are the prettiest lady in all of the heath, and would make me the finest wife, from the river Eyre to the tall mountains in the north."

"Why, sir, you flatter me, but to what purpose?" Catherine was beginning to enjoy exchanging words with the handsome Captain of the Horse Guards.

"My purpose you ask, my lady? Only to win your heart!" Declared the handsome young man. He swept his hat from his head and bowed low from the waist. "I must win your heart to replace the very heart which I have lost to you."

"Lost your heart? Why what can you mean?" Catheri

Drat: Well, it's happened again. The Physics Kahuna is perfectly aware that the preceding paragraphs are utter nonsense and have no place at all in a quality work of science education such as the various chapters you have been studying throughout the year. A most sincere apology is offered.

We have done a lot of work with energy, but the type of energy we've dealt with has been mechanical energy. It is time now to look into other types of energy. Thermal energy has to do with the internal energy of a system – the energy of the particles that make a thing up.

Thermal Energy $\equiv$ The total kinetic energy of the particles in a system

The particles that make up a system are the molecules, atoms, or ions that make it up. These particles have kinetic energy – they have motion. In a gas, the particles are free to zoom around and bounce off other particles. In a liquid they also flit about, but they also make weak bonds with each other and tend to clump together. In a solid the particles are bound together with chemical bonds. These bonds are not rigid, however, so the particles can move back and forth. Kind of like they're connected to each other with springs that allow them to vibrate.

Thermal Definitions: Here are some important definitions:

> ***Thermal Contact* ≡ *two systems are placed so that they can exchange thermal Energy***
> ***Heat* ≡ *thermal energy transferred from one system to another.***
>
> ***Temperature* ≡ *average kinetic energy of the particles in a system.***
>
> ***Thermal equilibrium* ≡ *A static state. Objects in thermal contact reach the same average internal energy state and no longer exchange thermal energy.***

Temperature: Instruments that measure temperature are called thermometers. There are several temperature scales that are in use around the world - the Celsius scale, Fahrenheit scale, Kelvin scale, and the Rankine scale are the major ones.

We will make use of the Celsius scale and the Kelvin scale. The other two scales are only used in the US of A, so we can safely ignore them. (Who cares about a country so backward that they don't even use the metric system?)

The Celsius scale was originally set up to monitor temperatures on the earth's surface. The zero point on the scale is fixed at the freezing temperature of water and 100° C is the boiling temperature of the good old H_2O (at one atmosphere pressure). The zero on this scale is arbitrary and has no physical meaning as a zero value (zero is supposed to be when you have "nothing", right?)

Temperatures using the Celsius scale are reported as ***degrees Celsius***. One would say, "Hey, the temperature today is twenty-three degrees Celsius!

The Kelvin scale has a true zero, its zero value represents the lowest possible temperature, which is known as ***absolute zero***. Absolute zero represents the minimum possible energy state for matter.

When reporting a Kelvin temperature, one would say, "Hey it's three hundred and one Kelvins outside! You don't use the word "degree" with a Kelvin temperature.
The size of the units for each scale are the same.

Absolute zero, which is zero Kelvins, is –273.15°C. The freezing point of water, 0°C is 273.15 K. Converting between the scales is simple, to convert Celsius to Kelvins you just add 273.15 and to convert Kelvins to Celsius you subtract 273.15.

$$T_K = T_C + 273.15 \qquad\qquad T_C = T_K - 273.15$$

When heat is added to a system, the particles gain kinetic energy. Since their average kinetic energy increases, the temperature increases. Since the particles have increased their kinetic energy, they move faster and further. Each particle takes up more room, so the object as a whole expands.

It expands in all directions.

Engineers and architects have to allow for the expansion of materials with temperature increases when they design things – or else the whole thing could break apart on a cold or hot day. Long structures like bridges have expansion joints to allow for the expansion of the structure with changing temperatures.

Many devices make use of the expansion of materials. Bimetallic strips are used to control the operation of cooling or heating devices. A bimetallic strip is made of two metals that are bonded together. Each metal expands a different amount, so one of the metals expands more than the other. This causes the strip to curve when the temperature changes. This can be used to switch electrical circuits on and off, controlling an air conditioner or a heater.

Heat Flow: Heat can flow from one system to another only if there is a temperature difference between the two systems. The greater the difference in temperature, the faster heat will flow.

$$\Delta T \equiv temperature\ difference$$

$$\Delta T = T_{Hot} - T_{Cold} \qquad or \qquad \Delta T = T_H - T_C$$

The direction of heat flow is from a high temperature system to a low temperature system. Heat can only flow in this direction. There is no logical reason for this; after all, isn't it reasonable to think that in the winter heat ***could*** flow from the cold outside into the warm inside of your house? It would cut your energy bill. Unfortunately, that will never happen.

Heat flows from the high temperature system to the low temperature system.

When an object absorbs heat, its particles must somehow gain kinetic energy. They do this by absorbing heat. There are three ways that heat can be transferred between systems: ***conduction***, ***radiation***, and ***convection***. The Physics Kahuna hopes that you are familiar with these. This is the kind of stuff that you do in elementary science classes.

Conduction is heat transfer by direct contact between two systems. When you sit on a really hot car seat and burn your hide, you have gained heat via conduction. Heat will flow from the hot system to the cold system until thermal equilibrium is reached. At that point heat will no longer flow.

What happens in conduction is that the particles in the hot object, placed against the cold object, have collisions with the particles in the cooler system. In these collisions, the particles in the high temperature system lose energy and the particles in the low temperature system gain energy. The thermal energy transfers through the cool system via collisions between the particles until the particles in the two systems have the same average kinetic energy. We say that the systems have reached thermal equilibrium when this happens.

Radiation is heat transfer via electromagnetic waves. A great deal of the energy from the sun reaches the earth in the form of electromagnetic waves. They travel through space. When you go outside on a warm spring day and bask in the warmth of the sun, you are absorbing heat that has radiated from the sun. Electric space heaters that have those glowing red heat elements provide most of their heat via radiation in the same way. Most of the heat that you get from a fireplace (or a camp fire for that matter) arrives via radiation.

The electromagnetic waves travel through space and are absorbed by the system, the absorbed energy is converted into the kinetic energy of the particles – makes them move back and forth.

Convection is heat transfer via fluid flow. A fluid absorbs heat at one location and then flows to another place where it transfers the heat it absorbed to some other system. Convection is used to heat homes via forced air furnaces. A large fan blows warm air into the rooms of the house through ducts. Cooler air is drawn in through grates and returned to the furnace for heating.

Ovens do most of their heating via conduction. An element in the bottom of the oven heats air. The heated air then circulates around and around in the oven transferring heat to the food you want to cook.

It is quite common to have multiple forms of heat transfer in a system. Burning gasoline in a car engine heats the engine block by conduction. Water is circulated through water channels in the engine block absorbing heat via conduction. It then carries the heat to the radiator – this is convection. The heat is then transferred from the water to the radiator via conduction. Air circulates through the radiator removing heat via conduction (when the air is in direct contact with the metal fins of the radiator). The heated air then departs, removing the heat from the radiator via convection.

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.

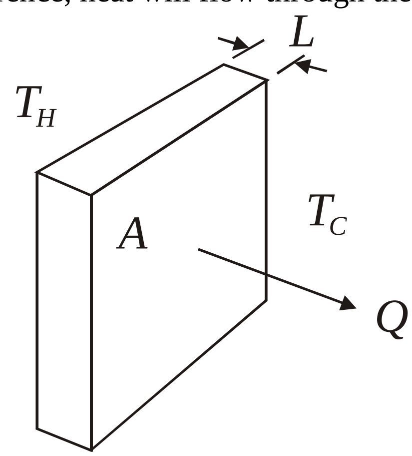
Gases make very good insulators because there aren't many particles to carry the energy from one place to another.

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:

$$H = \frac{Q}{t}$$

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: $H = kA\frac{\Delta T}{L}$

> 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 $H = kA\frac{\Delta T}{L}$ and $H = \frac{Q}{t}$, Then $Q = H\,t$ so, substituting in for *H*, we get:

$$Q = k\ A\,t\,\frac{\Delta T}{L}$$

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 $\frac{W}{m \cdot K}$ or $\frac{J}{m \cdot s \cdot {}^{o}C}$

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

- A brick oven is 15.0 cm thick. The inside temperature is 350.0 °C. The outside temperature is 25.0 °C. How much heat is lost from one side of the oven in one hour? The side measures 85.0 cm x 60.0 cm. Thermal conductivity of brick? Use 0.71 J/s·m·°C.

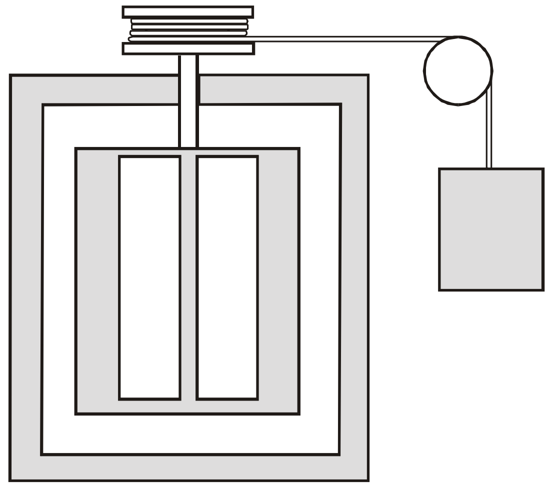
$$Q = k\,A\,t\,\frac{\Delta T}{L} \quad Q = 0.71\frac{J}{\cancel{m}\,\cancel{s}\,{}^{o}C}\left(0.85\,\cancel{m}\right)\left(0.60\,\cancel{m}\right)\left(3\,600\,\cancel{s}\right)\frac{\left(350.0\,{}^{o}\cancel{C} - 25.0\,{}^{o}\cancel{C}\right)}{0.15\,\cancel{m}}$$

$$Q = 2\,824\,000\,J = \boxed{2\,820\,kJ}$$

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:

$$1\,cal = 4.186\ J$$

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.

(a) $$2\left(876\ \cancel{Cal}\right)\left(\frac{1\,000\ \cancel{cal}}{1\ \cancel{Cal}}\right)\left(\frac{4.186\ J}{1\ \cancel{cal}}\right) = \boxed{7\,330\,000\ J}$$

That's a lot of joules!

(b) $$W = mgy \qquad y = \frac{W}{mg} = \frac{7\,330\,000\ Nm}{58\ kg\left(9.8\,\frac{m}{s^2}\right)} = 12\,896\,\frac{\cancel{N}m}{\cancel{N}} = \boxed{13.0\ km}$$

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 Physics Kahuna thinks that it is on the next page or else one of the others.

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

$$Q = mc\Delta T$$

> ***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?

We're not asked to find the final temperature, just the temperature change, so we solve for ***ΔT***.

$$Q = mc\Delta T \quad \Delta T = \frac{Q}{mc}$$

$$\Delta T = 34\,\cancel{kJ}\left(\frac{1}{2.5\,\cancel{kg}}\right)\left(\frac{1}{4.186\,\dfrac{\cancel{kJ}}{\cancel{kg}\cdot {}^{o}C}}\right) = \boxed{3.2\ {}^{o}C}$$

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: $$Q_{Lost} = Q_{Gained}$$

- 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?

$$Q_{lost} = Q_{Gained} \qquad m_g c_g \Delta T_g = m_w c_w \Delta T_w$$

$$m_w = \frac{m_g c_g \Delta T_g}{c_w \Delta T_w} = \frac{\left(0.250\,\cancel{kg}\right)\left(0.129\,\frac{k\cancel{J}}{\cancel{kg}\cdot{}^{o}\cancel{C}}\right)\left(125^{o}\cancel{C} - 25^{o}\cancel{C}\right)}{\left(4.186\,\frac{k\cancel{J}}{kg\cdot{}^{o}\cancel{C}}\right)\left(25^{o}\cancel{C} - 22^{o}\cancel{C}\right)}$$

$$m_w = \boxed{0.26\,kg}$$

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

- 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?

$$Q_{lost} = Q_{Gained} \qquad m_B c_B \Delta T_B = m_w c_w \Delta T_w \qquad \Delta T_w = \frac{m_B c_B \Delta T_B}{m_w c_w}$$

$$\Delta T_w = \frac{\left(0.158\,\cancel{kg}\right)\left(0.384\,\frac{\cancel{J}}{\cancel{kg}\cdot{}^{o}\cancel{C}}\right)\left(265\,{}^{o}C - 35.5\,{}^{o}C\right)}{\left(0.550\,\cancel{kg}\right)\left(4.186\,\frac{\cancel{J}}{\cancel{kg}\cdot{}^{o}\cancel{C}}\right)} = 6.05\ {}^{o}C$$

$$\Delta T_w = T_f - T_i \qquad T_i = T_f - \Delta T_w \quad = 35.5\ ^oC - 6.05\ ^oC \quad = \quad \boxed{29.4\ ^oC}$$

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:

$$Q = mL$$

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

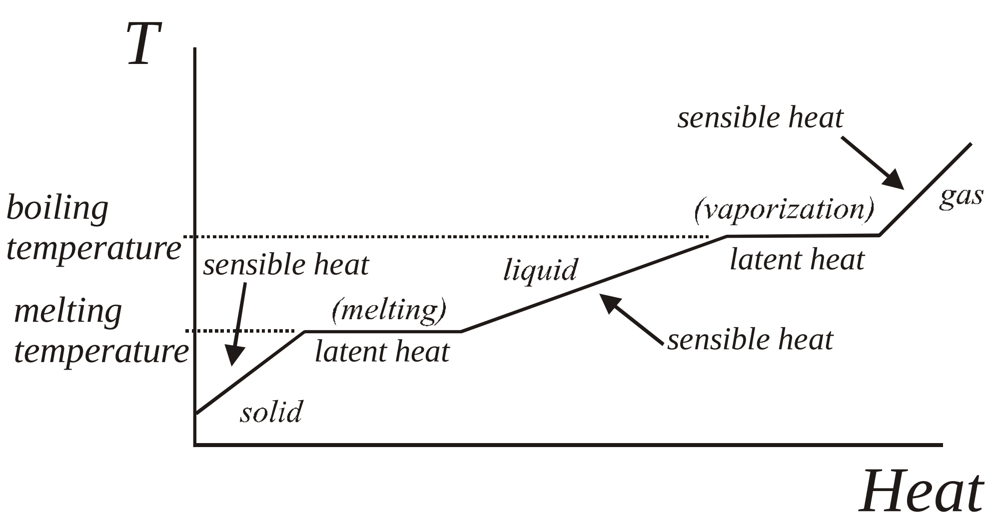
The latent heat of vaporization has this symbol: $\boldsymbol{L_v}$

The latent heat of fusion has this symbol: $\boldsymbol{L_f}$

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?

This is a simple problem. Just use the phase change equation.

$$Q = mL_f \quad = 2.85\,\cancel{kg}\left(333\frac{kJ}{\cancel{kg}}\right) \quad = \quad \boxed{949\,kJ}$$

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.

Dear Cecil:
I am a member of a small group which meets Sunday afternoons to read aloud the novels of Charles Dickens. Last week we reached chapter 32 of *Bleak House*. In this chapter, a rather low character by the name of Krook dies by--get this--spontaneous combustion. All that remains of him is a small heap of cinder and ash.

I was delighted, but since then I have been looked at rather pathetically by everyone I've reported it to. No one believes it to be possible. Well, Cecil, if it is an actual phenomenon, then why hasn't anyone heard of it? If it isn't, how did the notion start and how was our dear Mr. Dickens led astray? --Scott E., Chicago

Cecil replies:
Spontaneous human combustion (SHC for short) is one of those twilight zone-type phenomena that people tend to lump with ectoplasm and telekinesis, so discussion has been confined largely to the nutcake journals. Nonetheless, a considerable body of evidence suggests that something like SHC actually occurs.

Over the past 300 years, there have been more than 200 reports of persons burning to a crisp for no apparent reason. The victims are discovered as piles of ashes and oily residue, completely consumed except for an occasional unburnt arm or leg.

Although temperatures of about 3,000 degrees Fahrenheit are normally required to char a body so thoroughly (crematoria, which usually operate in the neighborhood of 2,000 degrees, leave bone fragments which must be ground up by hand), frequently little or nothing around the victim is damaged, except perhaps the exact spot where the deceased ignited. SHC victims have burnt up in bed without the sheets catching fire, clothing worn is often barely singed, and flammable materials only inches away remain untouched.

According to researcher Larry Arnold, the first medical report of SHC appeared in *Acta Medica & Philosophica Hafniensia* in 1673. A hard-drinking Parisian was found reduced to ashes in his straw bed, leaving just his skull and finger bones. The straw matting was only lightly damaged. Since then many other occurrences have been noted. Charles Dickens, in doing research for Bleak House, found 30 cases on record.

Here are some typical SHC reports:

- On April 9, 1744, Grace Pett, 60, an alcoholic residing in Ipswich, England, was found on the floor by her daughter like "a log of wood consumed by a fire, without apparent flame." Nearby clothing was undamaged.
- On May 18, 1957, Anna Martin, 68, of West Philadelphia, Pennsylvania, was found incinerated, leaving only her shoes and a portion of her torso. The medical examiner estimated that temperatures must have reached 1,700 to 2,000 degrees, yet newspapers two feet away were found intact.
- On December 5, 1966, the ashes of Dr. J. Irving Bentley, 92, of Coudersport, Pennsylvania, were discovered by a meter reader. Dr. Bentley's body apparently ignited while he was in the bathroom and burned a 2-1/2-by-3-foot hole through the flooring, with only a portion of one leg remaining intact. Nearby paint was unscorched.

Perhaps the most famous case occurred in St. Petersburg, Florida. Mary Hardy Reeser, a 67-year-old widow, spontaneously combusted while sitting in her easy chair on July 1, 1951. The next morning, her next door neighbor tried the doorknob, found it hot to the touch and went for help. She returned to find Mrs. Reeser, or what was left of her, in a blackened circle four feet in diameter. All that remained of the 175-pound woman and her chair was a few blackened seat springs, a section of her backbone, a shrunken skull the size of a baseball, and one foot encased in a black stain slipper just beyond the four-foot circle. Plus about 10 pounds of ashes.

The police report declared that Mrs. Reeser went up in smoke when her highly flammable rayon-acetate nightgown caught fire, perhaps because of a dropped cigarette. But one medical observer declared that the 3,000-degree heat required to destroy the body should have destroyed the apartment as well. In fact, damage was minimal--the ceiling and upper walls were covered with soot. No chemical accelerants, incidentally, were found.

No satisfactory explanation of SHC has been offered. Many SHC victims have been alcoholics, and at one time it was thought that alcohol or its derivatives in the body simply ignited. But experiments in the 19th century demonstrated that flesh impregnated with alcohol will not burn with the intense heat associated with SHC. Other theories involve deposits of flammable body fat--many victims have been overweight. But others have been skinny.

One school of thought blames phosphorous. One of the Teeming Millions explains: "SHC is thought to be the result of an error in phosphorous metabolism. As you may recall from your college biochemistry, living creatures store accessible energy in phospho-diester bonds. Under certain conditions, improperly manufactured polyphosphorous compounds in all the body cells can undergo an autocatalytic reaction. Water will not stop SHC. To get an idea of what's happening, have a chemist drop polyphosphoric acid in water." Unfortunately, I have scoured the recent scientific literature in vain for any discussion along these lines. Biochemists I have spoken to reject the idea out of hand.

So the question remains open. At least nobody's claiming that UFOs or the spirit world are involved. You may rely on Uncle Cecil to keep you abreast of future developments.

UPDATE
I said I'd keep you up to date on spontaneous human combustion (SHC). You thought I was kidding?

Past SHC researchers have blamed everything from excessive alcohol consumption to "geomagnetic fluctuations." Now Joe Nickell and John Fischer, the former a well-known investigator of the paranormal, have analyzed the evidence in 30 cases and concluded that SHC may not be so inexplicable after all.

Here's a rundown of their findings, as published in the *Skeptical Inquirer*:

- In most cases combustion probably wasn't spontaneous. Candlesticks, oil lamps, pipes, and the like were often found near the victims. Mrs. Reeser when last seen alive was smoking a cigarette.
- The victims tended to be slow to react. Many were alcoholics; others were elderly, overweight, or handicapped in some way. Mrs. Reeser was 67, weighed 175 pounds, and had a bad leg. The evening before her demise she told her son she had taken two sleeping pills and expected to take two more.
- Bodies can be totally consumed at temperatures much lower than previously believed. Proponents of paranormal explanations for SHC often point out that crematoriums use temperatures of 2,000 degrees or more, much hotter than the usual household fire. But experts say high temps are necessary only if the body must be destroyed in a short time. Smoldering fires can consume an entire piece of furniture (and presumably the body within it) if given long enough. Yet they often leave nearby objects undamaged. Twelve hours

passed between the time Mrs. Reeser was last seen alive and the time her remains were discovered.

- In cases where the body was completely destroyed, there was often a nearby source of combustible material to feed the fire. The floorboards beneath a number of victims were found burnt through; Mrs. Reeser was wearing a flammable nightgown and housecoat and was sitting in an overstuffed chair. In addition--this gets pretty gross--the fuel sources may have served to catch melting body fat which then added to the flames. Call it the "candle effect." A quantity of "grease," Nickell and Fischer note, was found where Mrs. Reeser's chair had stood.

"In the Reeser case, what probably happened was that the chair's stuffing burned slowly, fueled by the melted body fat and aided by partially open windows," Nickell and Fischer conclude. "What has been described as 'probably the best-documented case' of alleged spontaneous human combustion is actually attributable to the deadly combination of a lit cigarette, flammable nightclothes, and sleeping pills."

Grisly stuff, but I thought you'd want to know.
--CECIL ADAMS

Invictus

Out of the night that covers me,
    Black as the Pit from pole to pole,
I thank whatever gods may be
    For my unconquerable soul.

In the fell clutch of circumstance
    I have not winced nor cried aloud.
Under the bludgeonings of chance
    My head is bloody, but unbowed.

Beyond this place of wrath and tears
    Looms but the horror of the shade,
And yet the menace of the years
    Finds, and shall find me, unafraid.

It matters not how strait the gate,
    How charged with punishments the scroll,
I am the master of my fate;
        I am the captain of my soul.

---- Williams Ernest Henley

Requiem

Under the wide and starry sky
Dig the grave and let me lie:
Glad did I live and gladly die,
And I laid me down with a will.

This be the verse you grave for me:
Here he lies where he long'd to be;
Home is the sailor, home from the sea,
And the hunter home from the hill.

-- Robert Louis Stevenson

Not in Vain

If I can stop one heart from breaking,
    I shall not live in vain:
If I can ease one life the aching,
    Or cool one pain,
Or help one fainting robin
    Unto his nest again,
    I shall not live in vain.

-- Emily Dickinson