**Thermodynamics**

From Science Olympiad Student Center Wiki

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*This page contains a large number of equations and mathematical symbols, which may take some time to load.*

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| |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Thermodynamics** | | | | | | **Physics & Lab Event** | | | | | | **Forum Threads** | [2018](https://scioly.org/forums/viewtopic.php?f=264&t=10872) |  |  |  | |  | [2013](http://www.scioly.org/phpBB3/viewtopic.php?f=142&t=3692) | [2012](http://scioly.org/phpBB3/viewtopic.php?f=127&t=2951) | [2011 (Preliminary)](http://www.scioly.org/phpBB3/viewtopic.php?f=92&t=2975) | |  |  |  |  | | **Tests** |  | |  | | |  | | | | | There are no images available for this event |  | | | | | **Question Marathons** | [2018](https://scioly.org/forums/viewtopic.php?f=266&t=10926) | [2017 (Prelim)](https://scioly.org/forums/viewtopic.php?f=228&t=10886) |  |  | |  |  |  |  | | [**Division B**](https://scioly.org/wiki/index.php/Division_B) **Champion** | [Beckendorff Junior High School](https://scioly.org/wiki/index.php/Beckendorff_Junior_High_School) | | | | | [**Division C**](https://scioly.org/wiki/index.php/Division_C) **Champion** | [Harriton High School](https://scioly.org/wiki/index.php/Harriton_High_School) | | | | |

**Thermodynamics** is a [Division B](https://scioly.org/wiki/index.php/Division_B) and [Division C](https://scioly.org/wiki/index.php/Division_C) event in which teams design and build a device to insulate a beaker of hot water, and take a test on concepts of thermodynamics. It was first run as a national event in [2012](https://scioly.org/wiki/index.php/2012) and [2013](https://scioly.org/wiki/index.php/2013) (with the Division B version being known as **Keep the Heat**) after being run as trial events in past years, and is set to return for the [2018](https://scioly.org/wiki/index.php/2018) season.

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**Overview**

In this event you create a model or device that simply insulates a 250ml Pyrex beaker filled with 100ml of hot water. Your goal is to create a device that loses the least amount of heat after a period of time determined by the instructor (20-30 minutes). While your device is being tested you take a short test on heat (conversions, specific heat, etc). The starting temperature can be anything from 60 degrees Celsius to 90 degrees Celsius (determined by the instructor). Participants will also need to estimate the amount of heat lost according to graphs made prior to the competition (see "Construction").

The Thermodynamics test can have many different topics on it. The test may include: temperature conversions, definitions of heat units, heat capacity, and specific heat calculations.

For both Division B and C, participants may use any notes that are hole punched and secured in a 3-ring binder of any size. A calculator (of no specifications) may also be used.

**Device**

The device portion for Thermodynamics and Keep the Heat requires constructing an insulating device for water.

The device must fit inside a 15 cm cube for Division C, or a 20 cm cube for Division B. If it does not fit, the device will be disqualified. The competitors must bring two identical 250 mL Pyrex beakers (or similar), which must fit in the device and be easily insertable and removable. There should also be easy access to the interior of the device for temperature measurement by the instructor - this is specified in the rules as a hole of a certain diameter at the top of the device, with the beaker being less than a certain distance below the top of the hole. The hole may be partially obstructed, so long as the measuring device can enter.

**Device Construction Tips**

* The thermal resistance of most common material can be found [on Wikipedia](https://en.wikipedia.org/wiki/R-value_(insulation)), with higher R values meaning a better insulator. However, testing and experimenting is needed to find the best material available.
* Keep the device easy to assemble and disassemble: the device may be disassembled after the event for inspection.
* The starting temperature of the internal beaker can be adjusted using the ice water.

**Device Testing**

The device for Thermodynamics and Keep the Heat must be [impounded](https://scioly.org/wiki/index.php?title=Impound&action=edit&redlink=1). At the beginning of the time slot, the event supervisor provides each team with hot water, of a specified temperature and volume (within limits imposed by the rules, and told to the competitors) to pour into each of the beakers. The teams must place one beaker inside their device and the other outside (as a control), and leave for a specified amount of time (again, within limits imposed by the rules, and told to the competitors). Teams will then estimate the final temperature of the internal beaker.

In Division C, teams are also given an option to add some ice water to their internal beaker (an amount of their choosing, within limits imposed by the rules) for bonus points.

The score in device testing is the sum of:

* Plot Score, based on completeness on the plots teams submit.
* Heat Retention Score, based on the ratio of the temperatures of the internal and external beakers, where a higher internal temperature is more desirable.
* Prediction Score, based on the accuracy of the team's final internal temperature estimate.
* In Division C, ice water bonus, based on the amount of ice water added to the internal beaker.

**Documentation**

Prior to the competition, teams make cooling curve graphs for various starting temperatures so they can easily identify the final temperature at the competition. 4 of these plots are to be submitted at competition, which are scored based on completeness.

**Basics of Thermodynamics**

Thermodynamics is the study of thermal energy along with how it interacts with matter and energy (Another definition is Lord Kelvin's, and that is: "Thermo-dynamics is the subject of the relation of heat to forces acting between contiguous parts of bodies, and the relation of heat to electrical agency.")

**The Four Laws of Thermodynamics**

There are four basic laws of thermodynamics that apply to any situation that meets the requirements of the specific laws. The laws actually start with the zeroth law and end with the third since the zeroth law was created later.

**Zeroth Law of Thermodynamics:** "If two systems are each in thermal equilibrium with a third, they are also in thermal equilibrium with each other."

This law is rather self explanatory, but it can be represented in math as: if

*a*=*c*a=c

and

*b*=*c*b=c

,

*a*=*b*a=b

(which is similar to the transitive property of equality). The zeroth law helps define the notion of temperature.

**First law of thermodynamics:** "A change in the internal energy of a closed thermodynamic system is equal to the difference between the heat supplied to the system and the amount of work done by the system on its surroundings."

This basically means that if a closed system receives more net heat than net work that it does, it would gain internal energy, and if the net work exceeds net heat intake, the closed system would lose energy (This can be represented in mathematics where i=change in internal energy, q=net heat intake, and w=net work as:

*i*=*q*−*w*i=q−w

, and that means that when

*q*>*w*q>w

,

*i*>0i>0

. In addition,

*i*<0i<0

when

*q*<*w*q<w

, and

*i*=0i=0

when

*q*=*w*q=w

.) One factor that supports this law is the Law of conservation of Energy.

**Second Law of Thermodynamics:** "Heat cannot spontaneously flow from a colder location to a hotter location."

This law explains entropy in that as the temperature of one object nears the temperature of another object, the amount of entropy increases increases, and this entropy must be decreased in order for work to be done. One example for this is a steam engine. As a steam engine is used, the metal and water in the steam engine will retain heat until the temperature of the metal and water is equivalent to the temperature of the fire that they are above. This waste heat can be removed by either the usage of cooling water or shutting the steam engine down until it cools down to a fair temperature.

**Third Law of Thermodynamics:** "As a system approaches absolute zero, all processes cease and the entropy of the system approaches a minimum value."

The importance of this law is that it proves that it is impossible for an object reach absolute zero. The reason for this is that as an object reaches lower temperatures, the molecular/atomic process slow which decreases heat transfer while the amount of work done (In this case it is molecular in the form of heat transfer.) decreases in an asymptotic approach and exponential decay due to the First and Second Laws of Thermodynamics. One example of this is that if there was an object at absolute zero touching another object that is significantly warmer, the warmer object would lose temperature in ever decreasing amounts as there is less energy for the warmer object to give to the colder object (The colder object also gains energy due to the Law of Conservation of Energy and would have less of a potential to receive energy.). That allows both of the objects' temperatures to be tracked using an exponential decay graph for the warmer object and a graph of exponential growth for the colder object (with temperature as the y axis and time as the x axis), and both graphs would have an asymptotic approach toward a certain temperature value (This situation is like constantly dividing 1,000,000 in half in an attempt to reach zero.). That means that an object can never be at absolute zero unless an object can be at a temperature lower than that (which is impossible due to the definition of absolute zero). This also implies that two objects that start out at different temperatures will never reach exactly equal temperatures, but measurement tools don't necessarily have the accuracy to detect those small differences. In addition, the way heat transfers between objects is dependent on the composition of the objects that the heat is going between.

Note: The wording of the laws is the specific wording used in the Wikipedia article for thermodynamics.

**The Many Gas Laws**

*For more detailed information, see* [*Chem Lab/Gas Laws*](https://scioly.org/wiki/index.php/Chem_Lab/Gas_Laws)

**Gay-Lussac’s Law:** states that the pressure of a given amount of gas held at constant volume is directly proportional to the Kelvin temperature.

>*PT*=*C*>PT=C

, therefore

*P*1*T*1=*P*2*T*2=*P*3*T*3...P1T1=P2T2=P3T3...

**Boyle’s Law:** states that the volume of a given amount of gas held at constant temperature varies inversely with the applied pressure when the temperature and mass are constant.

*PV*=*C*PV=C

, therefore

*P*1*V*1=*P*2*V*2=*P*3*V*3...P1V1=P2V2=P3V3...

**Charles’ Law:** states that the volume of a given amount of gas held at constant pressure is directly proportional to the Kelvin temperature.

*VT*=*C*VT=C

, therefore

*V*1*T*1=*V*2*T*2=*V*3*T*3...V1T1=V2T2=V3T3...

**Avogadro’s Law:** Gives the relationship between volume and amount of gas when pressure and temperature are held constant

**Hess’ Law:** states that the heat evolved or absorbed in a chemical process is the same whether the process takes place in one or in several steps. This is also known as the **law of constant heat summation**.

**Le Châtelier's Principle:** If a change is made to a system, then the system will react in such a way so as to absorb the force causing the change.

**Ideal Gas Law:** A combination of all the gas laws, applicable to any gas. Relates temperature, volume, and pressure to each other. A further derivation of this law is called van der Waals' equation.

*PV*=*nRT*PV=nRT

OR

*PV*=*nKT*PV=nKT

**van der Waals' Equation:** As there are attractive forces between molecules, the pressure is lower than the ideal value. To account for this the pressure term is augmented by an attractive force term a/V2. Likewise real molecules have a volume. The volume of the molecules is represented by the term b. The term b is a function of a spherical diameter d known as the van der Waals diameter. The van der Waals’ equation accounts for these inaccuracies.

(*P*+*n*2*aV*2)(*V*−*nb*)=*nRT*(P+n2aV2)(V−nb)=nRT

**Heat Theories**

There are two theories of heat, one obsolete, one valid.

**Caloric Theory of Heat**

The caloric theory of heat is an obsolete theory stating that heat is a fluid that flows from hot to cold substances. There are six assumptions of this caloric theory.

1. Heat is a fluid that flows from hot to cold substances

2. Heat has a strong attraction to matter, which can hold a lot of heat.

3. Heat is conserved.

4. Sensible heat causes an increase in the temperature of a system

5. Latent heat combines with particles in matter, which causes substances to melt or boil.

6. Heat is weightless. This is the ONLY true assumption.

Antoine Lavoisier came up with the caloric heat theory in the 1770’s. Heat was called “caloric”, and cold was called “frigoric”, or lack of caloric.

**Kinetic Theory of Heat**

The kinetic theory is a valid theory states that matter is comprised of molecules in constant, random motion. It comprises of the following assumptions:

1. The gas consists of very small particles, so the average distance between the gas particles is comparatively large.

2. These particles have the same mass.

3. The number of molecules is so large that statistical treatment can be applied.

4. These molecules are in constant, random, and rapid motion.

5. The rapidly moving particles constantly collide among themselves and with the walls of the container. All these collisions are perfectly elastic. This means, the molecules are considered to be perfectly spherical in shape, and elastic in nature.

6. Except during collisions, the interactions among molecules are negligible. (That is, they exert no forces on one another.) This implies the dynamics of the molecules can be treated classically. This means, the equations of motion of the molecules are time-reversible.

"The average kinetic energy of the gas particles is proportional to the temperature of the system and depends only on it."

7. The time during collision of molecule with the container's wall is negligible as compared to the time between successive collisions.

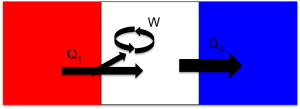
All the gas laws are derivable by the kinetic theory of heat.

The first version of the kinetic theory of heat was put out by August Krönig in 1856. He made a simple gas-kinetic model that only considered translational movement.

A later model was conceived by James Clerk Maxwell. In all technicalities, he is the father of the kinetic theory.

**Carnot Cycle**

One of the important things that helped with the creation of the Four Laws of Thermodynamics is the Carnot Cycle. A picture of the Carnot Cycle is shown below.

[](https://scioly.org/wiki/index.php/File:Carnot_Cycle.png)

The Carnot Cycle

In the above image, Q stands for heat, and W stands for work.

What is happening in the picture is that heat is being transferred from the warmer red square (at temperature

*T*1T1

) to the neutral white square where some of the heat remains in the form of work. The rest of the heat moves to the colder blue square (at temperature

*T*2T2

).

Due to the Law of Conservation of Energy (which has the implication that energy can't be created or destroyed and is sometimes stated as that), the amount of work done in the middle square must be equivalent to the heat transferred from the red square to the white square minus the heat transferred from the white square to the blue square. That can be mathematically represented as:

*W*=*Q*1−*Q*2W=Q1−Q2

. In addition, the amount of heat transferred and the amount of work done are proportional to temperature by the equation

*W*=*Q*1(1−*T*2*T*1)W=Q1(1−T2T1)

.

This makes logical sense in that as the temperatures of two objects near each other, the potential and amount of heat transfer decreases which would also decrease the amount of work done on the white square due to the Second and Third Laws of Thermodynamics. In addition, that equation can be altered so that you can find

*Q*2Q2

. The new equation would be:

*Q*2=*T*2*T*1*Q*1Q2=T2T1Q1

.

That can be further altered to show the proportion between temperature difference and heat transfer, and the equation for that is:

*Q*2*Q*1=*T*2*T*1Q2Q1=T2T1

. That can then be written as

0=*T*2*T*1−*Q*2*Q*10=T2T1−Q2Q1

, and then it can be changed to

0=*Q*1*T*1−*Q*2*T*20=Q1T1−Q2T2

. Since

*Q*2Q2

is a measure of heat output from the white square, it can be written as a negative number by using the white square as a reference point. That means that the equation can be turned into the inequality

*Q*1*T*1+*Q*2*T*2>0Q1T1+Q2T2>0

or the equality

*S*=*Q*1*T*1+*Q*2*T*2S=Q1T1+Q2T2

(where S equals entropy). The function of that equation and the inequality is entropy since it represents the part that is not work in the equation

*W*=*Q*1−*Q*2W=Q1−Q2

, because it is based off of the equation

*Q*2=*T*2*T*1*Q*1Q2=T2T1Q1

.

If you go back to the equation

*Q*2*Q*1=*T*2*T*1Q2Q1=T2T1

, you can alter it so that you can find any of those variables. The equations to do that are as follows:

*Q*2=*T*2*T*1*Q*1Q2=T2T1Q1

,

*T*1=*T*2*Q*2/*Q*1T1=T2Q2/Q1

,

*Q*1=*Q*2*T*2/*T*1Q1=Q2T2/T1

,

*T*2=*Q*2*Q*1*T*1T2=Q2Q1T1

**Importance**

Studies of the Carnot Cycle have caused the creation of the First and Second Laws of Thermodynamics. If you look at the equation

*W*=*Q*1−*Q*2W=Q1−Q2

, you can see that it shows heat flow in and out of the white square in the picture, and work in thermodynamics refers to energy transferred to a system that **changes** the system. This was restated later as the First Law of Thermodynamics. If you look at the equation for finding entropy,

*Q*1*T*1+*Q*2*T*2=*S*Q1T1+Q2T2=S

, and apply it to the Carnot Cycle while including the progression of time, you can see that as the Carnot Cycle goes on for longer periods of time,

*T*1T1

decreases towards

*T*2T2

which increases. In addition,

*Q*1Q1

and

*Q*2Q2

would decrease. This became the Second Law of Thermodynamics.

**Examples of Usage**

The equations in the Carnot Cycle can be used to determine the values for all 6 of the variables so long as you have the value for one temperature variable, one heat variable, and one other variable that is not the value for entropy.

Lets suppose in the Carnot Cycle that

*W*W

is 10 joules,

*Q*1Q1

is 40 joules, and

*T*1T1

is 400 degrees Kelvin. We can make a table of our information which is:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Information about variables in the Carnot Cycle | | | | | | |
| **variable** | *W*W  **(work)** | *Q*1Q1  **(heat)** | *Q*2Q2  **(heat)** | *T*1T1  **(temperature)** | *T*2T2  **(temperature)** | *S*S  **(entropy)** |
| **value** | 10 Joules | 40 Joules |  | 400 degrees Kelvin |  |  |

From there we can use formulas to find out the rest of the variables. The equation:

*Q*1=*W*+*Q*2Q1=W+Q2

can be used to find the value for

*Q*2Q2

. The equation with values for the variables is:

40=10+*Q*240=10+Q2

, and that can be simplified to

30=*Q*230=Q2

. The new table would therefore be:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Information about variables in the Carnot Cycle | | | | | | |
| **variable** | *W*W  **(work)** | *Q*1Q1  **(heat)** | *Q*2Q2  **(heat)** | *T*1[T1[  **(temperature)** | *T*2T2  **(temperature)** | *S*S  **(entropy)** |
| **value** | 10 Joules | 40 Joules | 30 Joules | 400 degrees Kelvin |  |  |

Then, the equation:

*Q*2=*T*2*T*1*Q*1Q2=T2T1Q1

can be used to find the value for

*T*2T2

. The equation with values for the variables is:

30=40*T*240030=40T2400

. The equation can then be simplified to:

0.75=*T*24000.75=T2400

, and that can be simplified to:

300=*T*2300=T2

. This answer can be verified by checking it with the equation:

*W*=1−*T*2*T*1*Q*1W=1−T2T1Q1

, and the equation with values for the variables is:

10=401−30040010=401−300400

. That can be simplified to

10=40(1−0.75)10=40(1−0.75)

which is equal to

10=0.25⋅4010=0.25⋅40

. That is equal to

10=1010=10

which means that

225=*T*2225=T2

. Therefore, the new table is:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Information about variables in the Carnot Cycle | | | | | | |
| **variable** | *W*W  **(work)** | *Q*1Q1  **(heat)** | *Q*2Q2  **(heat)** | *T*1T1  **(temperature)** | *T*2T2  **(temperature)** | *S*S  **(entropy)** |
| **value** | 10 Joules | 40 Joules | 30 Joules | 400 degrees Kelvin | 300 degrees Kelvin |  |

Finally, the equation

*S*=*Q*1*T*1+*Q*2*T*2S=Q1T1+Q2T2

can be used to find the value for S, and the equation with values for the variables is:

*S*=40400+30300S=40400+30300

. That can be simplified to

*S*=0.1+0.1S=0.1+0.1

, which is equivalent to

*S*=0.2S=0.2

. Therefore all of the values for the variables in a table is:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Information about variables in the Carnot Cycle | | | | | | |
| **variable** | *W*W  **(work)** | *Q*1Q1  **(heat)** | *Q*2Q2  **(heat)** | *T*1T1  **(temperature)** | *T*2T2  **(temperature)** | *S*S  **(entropy)** |
| **value** | 10 Joules | 40 Joules | 30 Joules | 400 degrees Kelvin | 300 degrees Kelvin | 0.2 Joules per Kelvin |

**Maxwell's Daemon**

Maxwell's Daemon is an imaginary creature that the mathematician James Clerck Maxwell created to contradict the second law of thermodynamics.

Suppose that you have a box filled with a gas at some temperature. This means that the average speed of the molecules is a certain amount depending on the temperature. Some of the molecules will be going faster than average and some will be going slower than average. Suppose that a partition is placed across the middle of the box separating the two sides into left and right. Both sides of the box are now filled with the gas at the same temperature. Maxwell imagined a molecule sized trap door in the partition with his minuscule creature poised at the door who is observing the molecules. When a faster than average molecule approaches the door he makes certain that it ends up on the left side (by opening the tiny door if it's coming from the right) and when a slower than average molecule approaches the door he makes sure that it ends up on the right side. So after these operations, he ends up with a box in which all the faster than average gas molecules are in the left side and all the slower than average ones are in the right side. So the box is hot on the left and cold on the right. Then one can use this separation of temperature to run a heat engine by allowing the heat to flow from the hot side to the cold side.

Another possible action of the demon is that he can observe the molecules and only open the door if a molecule is approaching the trap door from the right. This would result in all the molecules ending up on the left side. Again this setup can be used to run an engine. This time one could place a piston in the partition and allow the gas to flow into the piston chamber thereby pushing a rod and producing useful mechanical work.

This imaginary situation seemed to contradict the second law of thermodynamics. To explain the paradox scientists point out that to realize such a possibility the demon would still need to use energy to observe the molecules (in the form of photons for example). And the demon itself (plus the trap door mechanism) would gain entropy from the gas as it moved the trap door. Thus the total entropy of the system still increases.

The demon is trying to create more useful energy from the system than there was originally. Equivalently he was decreasing the randomness of the system (by ordering the molecules according to a certain rule) which is decreasing the entropy. No such violation of the second law of thermodynamics has ever been found.

**Joule's Laws**

Joule's Laws are two laws created by James Prescott Joule that describe the heat dissipation of components in an electrical circuit and how the internal energy of an ideal gas relates to temperature, pressure, and volume.

Joule's First Law:

*Q*=*tRI*2Q=tRI2

In that equation,

*Q*Q

is the heat dissipation of the component while

*I*I

is the electrical current through the component, and

*R*R

is the electrical resistance of the component while

*t*t

is the time that the electricity ran through the component. If the time is measured in seconds (

*s*s

is oftentimes used as the variable for seconds.), the variable

*Q*Q

will represent an answer in Joules (

*j*j

). Joule's first Law provides one way in which Electrical Engineering and Thermodynamics relate. In Electrical Engineering, the equation for finding the power in a circuit/component is:

*P*=*VI*P=VI

(where

*P*P

is power in watts,

*V*V

is volts, and

*I*I

is current or amperes.) which can be written as

*P*=*RI*2P=RI2

(where

*R*R

is the electrical resistance). That means that:

*J*=*Ps*J=Ps

(

*W*W

can also be used in place of

*P*P

.). This can be further proven by one definition of a volt (

*V*=*JC*V=JC

where

*C*C

represents Coulombs). One Ampere (amp) is equivalent to one Coulomb per second which means that the equation can be changed to:

*V*=*JIs*V=JIs

or

*J*=*VIs*J=VIs

which is equal to

*J*=*Ps*J=Ps

. The main importance of Joule's First Law is that it allows people to calculate the heat dissipation of electrical circuits/components.

Joule's Second Law: "The internal energy of an ideal gas is independent of its volume and pressure, depending only on its temperature."

Note: The wording of the laws is the specific wording used in the Wikipedia article for Joule's Laws.

**Important Concepts**

**Thermodynamic Systems**

A thermodynamic system is a region of the Universe with specific boundaries that is analyzed using thermodynamic theories, principles, and laws.

Everything that is not part of a thermodynamic system is said to be in the surroundings. The system and surroundings are separated by a boundary that may be fixed (always stays in the same spot), movable (location can change), imaginary (There is nothing separating the surroundings and the system, and the boundary is merely a designated space.), or real (The boundary is a physical object.)

There are five types of thermodynamic system, and each type allows different things to pass through the boundary. The types are:

**Open System:** In open systems, matter, heat, and work can cross the boundary to enter or exit the system. The First Law of Thermodynamics when applied to an open system is (quoting from Wikipedia): "the increase in the internal energy of a system is equal to the amount of energy added to the system by matter flowing in and by heating, minus the amount lost by matter flowing out and in the form of work done by the system."

**Closed System:** In a closed system, heat and work can cross the boundary, but matter can't cross the boundary. In addition, there is a type of boundary that may be in a closed system that heat can't cross, adiabatic, and one that work can't cross, rigid.

**Isolated system:** In an isolated system, neither matter, heat, or work can cross the boundary. Therefore, differences in thermal energy will typically lessen until the system reaches thermodynamic equilibrium.

**Diathermic Systems:** In a diathermic system, heat can cross the boundary, but nothing else.

**Adiabatic Systems:** In an adiabatic system, heat may not cross the boundary, but everything else can.

**Thermodynamic Processes**

An **isobaric process** occurs at constant pressure. An example would be to have a movable piston in a cylinder, so that the pressure inside the cylinder is always at atmospheric pressure, although it is isolated from the atmosphere. In other words, the system is dynamically connected, by a movable boundary, to a constant-pressure reservoir.

An **isochoric process** is one in which the volume is held constant, meaning that the work done by the system will be zero. It follows that, for the simple system of two dimensions, any heat energy transferred to the system externally will be absorbed as internal energy. An example would be to place a closed tin can containing only air into a fire. To a first approximation, the can will not expand, and the only change will be that the gas gains internal energy, as evidenced by its increase in temperature and pressure. We may say that the system is dynamically insulated, by a rigid boundary, from the environment. An isochoric process is also known as an **isometric process** or an **isovolumetric process**.

An **isothermal process** occurs at a constant temperature. An example would be to have a system immersed in a large constant-temperature bath. Any work energy performed by the system will be lost to the bath, but its temperature will remain constant. In other words, the system is thermally connected, by a thermally conductive boundary to a constant-temperature reservoir.

An **adiabatic process** is a process in which there is no energy added or subtracted from the system by heating or cooling. For a reversible process, this is identical to an isentropic process. We may say that the system is thermally insulated from its environment and that its boundary is a thermal insulator. If a system has an entropy which has not yet reached its maximum equilibrium value, the entropy will increase even though the system is thermally insulated. Under certain conditions, two states of a system may be considered adiabatically accessible.

An **isentropic process** occurs at constant entropy. For a reversible process, this is identical to an adiabatic process. If a system has an entropy value which has not yet reached its maximum equilibrium value, a process of cooling may be required to maintain that value of entropy.

**Branches of Thermodynamics**

There are several branches of thermodynamics, and each branch is about a specific aspect of thermodynamics.

**Classical Thermodynamics**

This is thermodynamics on a large or macroscopic scale. This branch of thermodynamics is used to model states and processes that are based on properties that can be measured, defined, and examined in a laboratory. These models include models based on the Four Laws of Thermodynamics and include: energy, mass, work, and heat exchanges.

**Statistical Thermodynamics**

This is thermodynamics on the molecular/atomic scale. This branch of thermodynamics explains how microscopic events, properties, and interactions influence Classical Thermodynamics.

**Chemical Thermodynamics**

This branch of thermodynamics is about how energy, within the subject of thermodynamics, influences chemicals and chemical reactions.

**Equilibrium Thermodynamics**

This branch of thermodynamics is about how matter and energy in a system change as the system approaches thermal equilibrium. One main goal in Equilibrium Thermodynamics is to figure out what a system will be like when it reaches thermodynamic equilibrium if you know the starting parameters for the system and the laws/forces that will act upon it.

**Non-Equilibrium Thermodynamics**

This branch of thermodynamics is the study of systems that aren't in thermal equilibrium, and many of the laws/theories/concepts are more general than the ones in Equilibrium Thermodynamics.

**Important People in Thermodynamics**

| **Important People in Thermodynamics** | | | |
| --- | --- | --- | --- |
| **Name** | **Born** | **Died** | **Achievements** |
| **James Prescott Joule** | 1818 | 1889 | Joule's discovery of the universality of the conversion between electrical and thermal energy (a landmark in itself) led directly to the dramatically important law of the conservation of all energy (1st law of Thermodynamics). The international unit of energy, the Joule, is named in his honor. |
| **Nicolas Leonard Sadi Carnot** | June 1, 1796 | August 24, 1832 | Sadi was a French engineer who, in his 1824 *Reflecting on the Motive Power of Fire*, gave the first successful theoretical account of heat engines, known as the *Carnot Cycle.* Often described as the Father of Thermodynamics, he is responsible for such concepts as Carnot efficiency, Carnot theorem, Carnot heat engine, and others. |
| **Rudolf Julius Emanuel Clausius** | 1822 | August 24, 1888 | Rudolf was a German physicist and Mathematician. Considered one of the central founders of Thermodynamics. His paper on the mechanical theory of heat, published in 1850, first stated the basic ideas of the Second law of Thermodynamics. In 1865, he introduced the concept of entropy. |
| **Walther Hermann Nernst** | June 25, 1864 | November 18, 1941 | He was a German physical chemist and physicist who is known for his theories behind the calculation of chemical affinity assembled as the third law of thermodynamics, for which he won the 1920 Nobel Prize in chemistry. He is also known for developing the Nernst equation. |
| **James Clerk Maxwell** | June 13, 1831 | November 5, 1879 | He was a Scottish physicist and mathematician. His most prominent achievement was formulating the classical electromagnetic theory. Also did a thought experiment called Maxwell’s Daemon. |
| **Daniel Gabriel Fahrenheit** | May 2, 1686 | November 5, 1879 | He was a Dutch, German, and Polish physicist, engineer, and a glass blower who is best known for inventing the alcohol thermometer and the mercury thermometer and for inventing a temperature scale that is named after him. He also created the first closed thermometer. |
| **Anders Celsius** | November 22, 1701 | April 25, 1744 | He was a Swedish astronomer. A professor of astronomy at Uppsala University from 1730-1741, but traveled from 1732-1735 visiting notable observatories in Germany, Italy, and France. He founded the Uppsala Astronomical Observatory in 1741, and in 1742 he proposed the Celsius temp. scale which takes his name. The scale was invented in 1745 by Linnaeus, one year after Celsius' death from tuberculosis. |
| **William Thompson (aka Lord Kelvin)** | June 26, 1826 | December 17, 1907 | He was a German physicist and engineer. His most well known contribution lies in founding absolute zero. He did important work in the mathematical analysis of electricity and formulation of the first and second laws of thermodynamics. He also coined the word “thermodynamics”. All absolute temperatures are stated units of Kelvin in his name. |
| **Galileo Galilei** | February 15, 1564 | January 8, 1642 | Created the first open thermometer. |

**Conversions and Equations**

This is an organized list of the ways to find different variables and convert from one unit to another (for convenience so that people don't have to look all through the article to find this information).

**Conversions**

|  |  |
| --- | --- |
| Acceleration | 1*m*/*s*2=100*cm*/*s*21m/s2=100cm/s2 |
| Area | 1*m*2=104*cm*2=106*mm*21m2=104cm2=106mm2 |
| Density | 1*g*/*cm*3=1*kg*/*L*=1,000*kg*/*m*31g/cm3=1kg/L=1,000kg/m3 |
| Energy, heat, work, internal energy, enthalpy | 1*kJ*=1000*J*=1000*N*⋅*m*=1*kPa*⋅*m*31kJ=1000J=1000N⋅m=1kPa⋅m3 |
| 1*kJ*/*kg*1kJ/kg | 1,000*m*2/*s*21,000m2/s2 |
| Force | 1*N*=1*kg*⋅*ms*21N=1kg⋅ms2 |
| Length | 1*m*=100*cm*=1,000*mm*1m=100cm=1,000mm |
| Mass | 1*kg*=1,000*g*1kg=1,000g |
| Power, heat transfer rate | 1*W*=1*J*/*s*,1*kW*=1,000*W*1W=1J/s,1kW=1,000W |
| Pressure | 1*Pa*=1*N*/*m*2,1*kPa*=1,000*kPa*,1*MPa*=1,000*kPa*1Pa=1N/m2,1kPa=1,000kPa,1MPa=1,000kPa |
| 1 atmosphere (atm) | 101.325*kPa*=760*torr*101.325kPa=760torr |
| Specific heat, entropy | 1*kJ*/*kg*⋅∘*C*=1*kJ*/*kg*⋅*K*=1*J*/*g*⋅∘*C*1kJ/kg⋅∘C=1kJ/kg⋅K=1J/g⋅∘C |
| Specific volume | 1*m*3/*kg*=1,000*L*/*kg*=1,000*cm*3/*kg*1m3/kg=1,000L/kg=1,000cm3/kg |
| Temperature | *TK*=*T*∘*C*+273.15TK=T∘C+273.15  ,  *T*∘*C*=59(*T*∘*F*−32)T∘C=59(T∘F−32)  ,  *T*∘*F*=95*T*∘*C*+32T∘F=95T∘C+32 |
| Velocity | 1*m*/*s*=3.6*km*/*hr*1m/s=3.6km/hr |
| Volume | 1*m*3=1,000*L*=106*cm*31m3=1,000L=106cm3 |

**Constants**

|  |  |
| --- | --- |
| Calorie | 4.186*J*4.186J |
| R (gas constant) | 8.314 J mol-1 K-1 |
| Boltzmann’s Constant | 1.38⋅10−23*J*/*K*1.38⋅10−23J/K |
| Avogadro’s Constant | 6.02⋅10236.02⋅1023 |
| Electron Volt (eV) | 1.60217646⋅10−19 joules1.60217646⋅10−19 joules |

|  |  |
| --- | --- |
| **Unit** | **Conversion** |
| Joule | Ways to convert other energy units into a Joule.   1. Multiply British Thermal Unit amount by 1,055 to get an approximation of the energy in Joules. 2. Multiply Small Calorie amount by 4.2 to get an approximation of the energy in Joules. 3. Multiply Large Calorie amount by 4,200 to get an approximation of the energy in Joules. |
| British Thermal Unit | Ways to convert other energy units into British Thermal Units.   1. Divide the amount of Joules by 1,055 to get an approximation of the energy in British Thermal Units. 2. Multiply Small Calorie amount by 0.003981042 to get an approximation of the energy in British Thermal Units. 3. Multiply Large Calorie amount by 3.981042654 to get an approximation of the energy in British Thermal Units. |
| Small Calorie | Ways to convert other energy units into Small Calories.   1. Divide the amount of Joules by 4.2 to get an approximation of the energy in Small Calories. 2. Multiply Large Calorie amount by 1,000 to get the amount of energy in Small Calories. 3. Multiply the British Thermal Unit amount by 251.1904762 to get an approximation of the amount of energy in Small Calories. |
| Large Calorie | Ways to convert other energy units into Large Calories.   1. Divide the amount of Joules by 4,200 to get an approximation of the energy in Large Calories. 2. Divide Small Calorie amount by 1,000 to get the amount of energy in Large Calories. 3. Multiply British Thermal Unit amount by 0.251190476 to get an approximation of the amount of energy in Large Calories. |
| Kelvin | Ways to convert other temperature units to Kelvin   1. Add 273.15 to the Celsius amount to get the temperature in Kelvin. 2. Add the Fahrenheit temperature to 459.67 and then multiply it by 5/9 to get the temperature in Kelvin. |
| Fahrenheit | Ways to convert other temperatures to Fahrenheit.   1. Multiply the Kelvin temperature by   9595  and then subtract 459.67 to get the temperature in Fahrenheit.   1. Multiply the Celsius temperature by   9595  and then add 32 to get the temperature in Fahrenheit. |
| Celsius | Ways to convert other temperatures to Celsius.   1. Subtract 273.15 from the temperature in Kelvin to get the temperature in Celsius. 2. Subtract 32 from the Fahrenheit temperature and then multiply it by   5959  to get the temperature in Celsius. |

**Equations**

This is a list of equations that define certain variables (Electrical Engineering variables are not included since heat dissipation of components is a minor point.).

|  |  |
| --- | --- |
| **Unit/Variable** | **Equations** |
| Joule (J) | *J*=*I*2⋅*R*⋅*s*J=I2⋅R⋅s    *J*=*M*⋅*m*J=M⋅m    *J*=*kg*⋅*m*2÷*s*2J=kg⋅m2÷s2    *J*=*P*⋅*s*J=P⋅s    *J*=*V*⋅*I*⋅*s*J=V⋅I⋅s    *J*=*V*⋅*C*J=V⋅C |
| Work (W) | *W*=*Q*1−*Q*2W=Q1−Q2  (from the [Carnot Cycle](https://scioly.org/wiki/index.php/Thermodynamics#Carnot_Cycle))  *W*=*Q*1(1−*T*2*T*1)W=Q1(1−T2T1)  (from the Carnot Cycle) |
| Entropy (S) | *S*=*Q*1*T*1+*Q*2*T*2S=Q1T1+Q2T2  (from the Carnot Cycle) |
| Heat (Q) | Q   * *Q*=*I*2⋅*R*⋅*t*Q=I2⋅R⋅t   (from [Joule's Laws](https://scioly.org/wiki/index.php/Thermodynamics#Joule.27s_Laws))  *Q*1Q1  *Q*1=*W*+*Q*2Q1=W+Q2  (from the Carnot Cycle)   * *QW*(1−*T*2/*T*1)QW(1−T2/T1)   *Q*1=*Q*2*T*2/*T*1Q1=Q2T2/T1  *Q*1=*T*1*Q*2*T*2Q1=T1Q2T2  *Q*2Q2  *Q*2=*Q*1−*W*Q2=Q1−W  (from the Carnot Cycle)   * *Q*2=*Q*1*T*2*T*1Q2=Q1T2T1   *Q*2=*T*2*Q*1*T*1Q2=T2Q1T1 |
| Temperature (T) | *T*1T1  *T*1=*Q*1*Q*2/*T*2T1=Q1Q2/T2  (from the Carnot Cycle)   * *T*1=*T*2*Q*2/*Q*1T1=T2Q2/Q1   *T*2T2  *T*2=*Q*2*Q*1/*T*1T2=Q2Q1/T1  (from the Carnot Cycle)   * *T*2=*T*1*Q*2*Q*1T2=T1Q2Q1 |

**Other Equations**

|  |  |
| --- | --- |
| **Concept** | **Equation** |
| **Gibbs' Free Energy** | Δ*G*=Δ*H*−*T*Δ*S*ΔG=ΔH−TΔS |
| **Carnot Efficiency** | *TH*−*TCTH*TH−TCTH |
| **Linear Expansion** | Δ*LL*0=*α*Δ*T*ΔLL0=αΔT |
| **Area Expansion** | Δ*AA*0=2*α*Δ*T*ΔAA0=2αΔT |
| **Volume Expansion** | Δ*VV*0=3*α*Δ*T*ΔVV0=3αΔT |

**Vocabulary**

**Absolute Zero:** The temperature at which all processes stop (defined in the third law of thermodynamics). This temperature is: 0 degrees Kelvin, -273.15 degrees Celsius, or -459.67 degrees Fahrenheit.

**Ampere (Amp, I):** The electrical charge of one coulomb in one second

**British Thermal Unit (abbreviated as BTU):** Roughly 1,055 joules or the amount of energy needed to get one pound of water from 39 to 40 degrees Fahrenheit.

**Caloric:** “Heat”, defined as a material thing. Hotness was thought of as “amount of caloric”. Obsolete.

**Coulomb (C):** The charge of an electrical current of one ampere in one second or the absolute value of the electrical charge of about 6.24\*10^18 protons or electrons (with protons having a positive charge and electrons having a negative charge).

**Enthalpy:** The total amount of energy in a system

**Entropy (when applied to thermodynamics):** The amount of heat that can't be used to do work; a measure of the randomness of a system.

**Equilibrium (thermodynamics):** The state of a system in which there is no flux.

**Frigoric:** “Cold”, defined as a material thing ALSO KNOWN AS lack of caloric

**Gibbs' Free Energy:** A thermodynamic quantity described as the amount of energy that can do work, or the amount of useful energy. Essentially the opposite of entropy.

**Heat (Q):** Energy that is transferred from one system to another in the form of internal energy due to differences in temperature. Can be measured in joules, British Thermal Units, small calories, or large calories. When it is a rate, watts is oftentimes used.

**Heat Capacity:** The amount of energy (in Joules) required to raise the temperature of a substance by 1° C. Also known as specific heat.

**Internal energy:** The energy of the motions of atoms and molecules within an object (includes potential energy of molecules and atoms in liquids and solids). Temperature is the measure of the internal energy of an object.

**Joule (J):** A unit of work equal to:

*N*⋅*m*N⋅m

,

*kg*⋅*m*2*s*2kg⋅m2s2

,

*P*⋅*s*P⋅s

,

*V*⋅*I*⋅*s*V⋅I⋅s

,

*V*⋅*C*V⋅C

, and

*s*⋅*R*⋅*I*2s⋅R⋅I2

(where N=Newtons, m=meters, kg=kilograms, s=seconds, P=watts, V=volts, I=amperes, C=Coulombs, and R=resistance in Ohms.).

**Large Calorie:** The amount of energy required to increase the temperature of one kilogram of water by one degree Celsius (about 4,200 joules).

**Latent Heat:** Heat in an object that you cannot sense

**Laws of Thermodynamics:** The fundamental laws that dictate how everything works in the world of thermodynamics

**Non-spontaneous Reaction:** A reaction that proceeds uphill. This reaction takes in more energy than it releases. Gibbs' Free Energy is positive. Also known as “endergonic”.

**Phlogiston:** A hypothetical substance thought to be formed when things are burned—obsolete.

**Quasistatic Process:** A hypothetical thermodynamic procession in which the system is always stable despite changes in the system.

**Resistance:** The amount that an object resists the flow of electric current

**Sensible Heat:** Heat in an object that you can sense

**Small Calorie:** The amount of energy required to increase the temperature of one gram of water by one degree Celsius (about 4.2 joules).

**Specific Heat:** The amount of energy needed to raise 1 kg of a substance 1 degrees Celsius. Also known as heat capacity.

**Spontaneous Reaction:** A reaction that proceeds downhill. This reaction releases more energy (as heat, light, etc.) than it takes in. Also known as “exergonic”.

**Temperature:** The average kinetic energy of an object

**Temperature Scale:** A continuum in algebraically equal intervals that gives a value to the average kinetic heat of an object

**Thermal Equilibrium:** When an object/system has an unchanging uniform temperature or when there is no exchange of heat when two objects/systems can exchange heat (In other words, they have the same temperature.).

**Thermodynamic Equilibrium:** When there are no net flows of matter or energy to or away from a system and no net changes in the matter and energy in that system.

**Torr:** A measure of pressure. 760 torr=1 atm.

**Work (W):** The energy transferred between systems that changes the system that it is transferred to (measured in joules).

**Volt (Voltage, V, E):** The energy required to move electrons from one location to another divided by the charge of the electrons in Coulombs. Can be stated as:

*V*=*IR*V=IR

,

*V*=*fJC*V=fJC

, and

*V*=*WI*V=WI

.

**Watt (P or W):** The electrical engineering unit for power that is equivalent to one joule per one second or one volt in a current of one ampere (

*P*=*Js*P=Js

and

*P*=*VI*P=VI

).

**Links**

[Minnesota Trial Rules for Keep the Heat](http://www.minnesotaso.org/Files/KEEP%20THE%20HEAT.pdf)

[Wikipedia-Thermodynamics](http://en.wikipedia.org/wiki/Thermodynamics)

[Hyperphysics-Thermodynamics](http://hyperphysics.phy-astr.gsu.edu/hbase/heacon.html)

[Wikipedia-Joule's Laws](http://http/en.wikipedia.org/wiki/Joule%27s_laws)

[Wikipedia-Entropy](http://en.wikipedia.org/wiki/Entropy)

[Chem Lab/Thermodynamics](https://scioly.org/wiki/index.php/Chem_Lab/Thermodynamics), for a more chemistry-oriented approach to thermodynamics