in a world of constant shortages one quantity remains an abundant supply it's called interview the science of thermodynamics is based on four fundamental postulates or axioms which are called the four laws of thermodynamics of these four laws the second law was discovered first and the first law is discovered second and the third to be discovered was called a zeroth law and the fourth law is called the third law now all that makes perfect sense because thermodynamics is the most implacably logical of all the sciences let me tell you briefly what those four laws are the zeroth law just says that the idea of temperature makes sense the first law is the conservation of energy the second law is the entropy principle and the third law says that there is a temperature so low that it can never be reached from these four laws people have deduced not only the properties of matter but the ultimate fate of the universe itself now if we're going to get anywhere on that today we had better get started Chalky's billiard academy an inner sanctum of sorts we're beyond the harsh glare of the limelight celebrities of sport dandies of high society and captains of industry gather to pursue a common interest one may wonder how those gentlemen managed to keep their names out of the newspapers to say nothing of the Lerner journals and the casual observer may ask what are nice guys like these doing in a place like this but to those in the know their purpose is obvious to investigate the laws of thermodynamics but why chocolates partly of course it's the ambiance which is the last word in understated elegance but that goes without saying mostly it's the equipment the specially called for apparatus that in the interests of science Chalky's always seems to have one hand even now to distinguished scientists whole beakers due to mature subject matter the following experiment should not be viewed much less conducted without parental consent held with the greatest care each beaker contains a small amount of experimental fluid which unfortunately is an acquired taste however before things began to get out of hand the fluid was poured into the beakers at a temperature of 295 kelvins and with scientific precision several geometrical cubes of crystalline h2o were added initial temperature of the crystals 273 Kelvin as time passes heat from the warm fluid flows into the cubes but the ice fails to warm up in response the cubes don't melt at once which stirs up a scientific controversy and of course this calls for more tests during 126 experiments but who's counting none of the chalky scientists can find a single instance of a warm ice cube but on the other hand they have found a dilution of the properties of the experimental fluid the ice staying at a constant temperature of 273 kelvin x' melts into liquid water as heat flows into it what accounts for this strange behavior in chocolate or for that matter everywhere else in the world eventually of course ice melts but along the way in its solid state why won't it warm up in any case in the end the ice the experimental fluid and in fact everything else reaches a state of equilibrium somewhere at least in theory there's a heavenly state called equilibrium but in the real world equilibrium is hard to find on a polynesian isle planet cranks up and liquid fire bubbles from down below and in the polar center of the Arctic Ocean the world's original ice machine works around the clock in the deep and darkest heart of equatorial the Sun Sears a Savannah with a relentless regularity and a shout away liquid thunders to the rocks below indeed from the beginning through the middle and to the ends of the earth the earth itself is a great machine a factory that never runs down never takes a break or goes on strike the engine of nature a powerhouse driven non-stop by the limitless energy of the Sun [Music] whether is trade winds of the great oceans or the diesel engines of the great ships that ply them all engines work because heat in motion can set matter into motion [Music] for several hundred years the heat engine has gone far and wide but past or present the heat itself goes only one way from high to low temperature [Music] the existence of any engine on earth including the earth itself depends on one of its parts working at a higher temperature than another in nature's engine for example powerful currents are driven through the Earth's atmosphere by the difference between the equator z-- temperature and the temperature at the poles from pole to pole and engine to engine the principle is the same in this vehicle it's the difference between the temperature of the exploding gasoline and air in its cylinders and the circulating water of its cooling system steam engines operate between the high temperature of the firebox and the low temperature of the atmosphere the bigger the difference in temperature the hotter and one part of the machine the cooler in another the better the engine works but if the fuel stops flowing and the hotter part of the engine is allowed to cool down the engine grinds to a halt and obviously that can spell trouble if every part of the engine has the same temperature if all motion ceases and there's no vitality left the engine reaches its final state the state of equilibrium from a scientific perspective then what's the picture in this molecular dynamics calculation each pair of atoms is programmed to interact with a realistic inter atomic force so then what really happens when a warm body is brought into contact with a cold one thermal energy spreads from warm to cold until both bodies reach the same temperature this is the state of thermal equilibrium at first glance thermal equilibrium seems different from the mechanical idea of stable equilibrium which keeps the body safe from falling but take a closer look when a falling body hits the ground each bounce is smaller than the last why because the kinetic energy of the body as a whole becomes transformed into the chaotic motions of the atoms that compose it and that process is very similar to heat flowing into a cold body and the end result is the same all of the available energy eventually becomes shared out as kinetic and potential energy of random motions of all the atoms therefore although the idea of equilibrium seems the ultimate in peace and serenity that view hides the seething motion of the atoms within so understanding equilibrium is a matter of perspective of seeing within and of seeing beyond [Music] because equilibrium is a state in which all temperatures are equal it's a place where no machines operate no geysers spray no volcanoes erupt no waterfalls no big engines want to do any work and no little engines can everywhere nature seems impelled toward the state of equilibrium hot bodies and cold ones striving toward the same temperature and falling bodies turning perfectly good work into useless heat from the physicists point of view when nature tends to behave in such a universal fashion there must be a scientific explanation and there is the explanation began as an idea of course an idea for the construction of a better steam engine there was a young man named car know whose logic was able to show for a work source proficient there's none so efficient as an engine that simply won't go city car knows greatest ideas never worked and in the real world probably never will yet he had the desire to create an engine as perfect as nature would permit and the logic to come pretty close given a difference in temperature a high temperature T sub I and a low temperature T sub o Carnot designed a perfect abstraction the Carnot engine takes in heat Q sub I at the high temperature turn some of it into work W and expels the rest q sub o as heat at the lower temperature because the Carnot cycle could run just as well in Reverse it was the picture of the ideal engine the most efficient machine the laws of nature could possibly permit but with car nose early death his ideas practically ignored from the beginning seemed destined for oblivion and that's probably where they would have ended had not two great scientists taken an interest in car nose theory Rudolf Clausius a German physicist and William Thompson the Glasgow professor of natural philosophy who would become Lord Kelvin rescued car nose original writings and from these very pages brought forth the science of thermodynamics within car nose reasoning Clausius and thompson saw an amazing fact and they saw it in terms of an astonishing mathematical simplicity in car nose ideal engine the ratio of the heat taken in to the heat wasted was the same as the ratio of the two absolute temperatures needed to drive the engine in other words and this was the ideal that stemmed from car nose imagination something that goes in is the same when it comes out. if it's not the heat and if it's not the temperature what is it it's the heat divided by the temperature at which it flows and according to Clausius that's entropy in a Carnot engine some entropy flows in at high temperature does its job and the same amount of entropy flows out at low temperature so an ideal engine not only conserves energy it conserves entropy as well that's the ideal but what about the reality in the real world with the clanking hissing whistling puffing engine what really happens for one thing all engines conserve energy the work equals the difference between the heat in and the heat leftover but using the same temperatures a real engine does much less work than car noise ideal it does less work and leaves more heat to release so even though the entropy that flows in might be the same as car knows the entropy that flows out is bigger that's an amazing fact the entropy that flows out of a real engine is bigger than the entropy that flows in could this mean that real engines create entropy out of nothing as a matter of fact yes that's because in real engines heat flow isn't isothermal power strokes aren't adiabatic and there's always friction between moving parts no matter what the final product will be all real engines manufacture entropy no matter the conditions in the workplace the supply of entropy always increases and no matter the workplace humans don't own the patent on the manufacture of entropy day in and day out mother nature's machines crank out entropy and nobody on earth can compete with her outfit every body of matter everywhere in the universe contains a certain amount of entropy and although it isn't always easy to tell just how much entropy a body has it isn't too hard to determine when entropy flows from one body to another if heat flows out of a body at temperature T the entropy of the body decreases by Q over T if heat flows in at temperature T the body's entropy increases by that amount throughout the cosmos when and where heat flows entropy close with it all engines extract heat from somewhere the Sun perhaps or the boiler of a ship use some other to do their work and then release the rest where the heats release doesn't matter too much not in the big scheme of things it flows into the atmosphere the C anywhere that's cool and too large to be affected very much by the door engines designed by humans operate pretty much the same way as the ones Mother Nature cooks up as long as heat flows from a high temperature to a lower one things keep rolling and as long as there's fuel coal or oil or wood or whatever works they'll keep rolling but if the fuel is cut off the heat ceases to flow the body cools it's temperature lowers little by little and when a body finally has the same temperature as its surroundings it's in a state of equilibrium as long as he flows as long as a warm body is warmer than the cool one entropy will increase and it will continue to increase until nothing else can possibly happen the state of equilibrium and should that happen entropy would increase no more in other words the state of equilibrium is the state of maximum entropy all of nature's processes can be seen as a constant drive to increase entropy all the time throughout the universe and though these facts have been well-established in most scientific circles a handful of dedicated researchers will not leave well enough alone perhaps that's because one fact still puzzles the most curious though ice melts as heat flows into it from the experimental fluid the ice doesn't warm up while there's any solid left why a flow of heat causes the transformation of ice into water at a constant temperature therefore in changing from ice the waters entropy is increased and so water is a state of higher entropy than ice in fact any solid is a state of lower entropy than the same matter in liquid form liquid is a more disordered chaotic state of matter than solid is and it has a higher entropy on land and sea or sea on land or indeed anywhere in the universe increasing entropy means increasing disorder and randomness and the ice itself it's a crystalline solid a state of matter in which molecules exist in a neat geometrically symmetric framework in a solid when the atoms cluster in the most favorable configuration the molecules are arranged to reduce their potential energy to a minimum but water is a very different picture remember liquid molecules are chaotic disarranged scattered and disorganized obviously liquid molecules don't minimize their potential energy as the solids do so liquids not only have more entropy than solids they also have higher potential energy and therefore more total energy to melt or not to melt that's the question and if the dynamic isn't quite yet as clear as crystal in this case an ice crystal look at it from the ice cubes point of view if the ice melts it becomes water a state of higher entropy and that's good because nature just loves to increase entropy but hold it before melting before becoming water the ice must also increase its energy which requires extracting energy from the rest of the universe but if energy in the form of heat flows out of the world into the ice it reduces the entropy of the rest of the universe and that's not good how bad is it well the entropy of the rest of the world decreases by the energy that flows divided by the temperature remember nature always wants to increase entropy in this case the entropy of the ice plus the rest of the universe if the temperature is very small it's very bad indeed melting the ice would cause a big decrease in entropy of the entire universe if the temperature is big it's not so bad the combined entropy increases when ice melts that's why in the grand scheme of things ice never melts at low temperature and ice never exists at higher temperature meanwhile back in Chalky's to say nothing of the universe as a whole there's a temperature somewhere in the middle a temperature at which neither ice nor water his favorite and it's the only temperature at which both ice and water can exist together which explains why these scientific beakers will never warm up until all the ice has melted so in the scientific language of chalkie's the quantity nature strives to maximize is not merely the entropy of the ice at a given temperature it is entropy minus the energy over the temperature of the ice as energy minus temperature times entropy of any sample gets smaller the entropy of the entire universe gets bigger e minus TS is called the free energy and although there really is no such thing as a free lunch there's plenty of free energy and every bit of matter in the world makes its own share of free energy as small as possible and that's what it takes to maximize the entropy of the universe so within the confines of a scientific ether as well as throughout the universe the law of increase of entropy drives matter from order to disorder for some time some have thought that the increasing entropy of the universe is driving the universe itself toward the ultimate state of disorder they call it the heat death of the universe and it's not a pretty sight it's a provocative notion dangerous to say the least so the question remains will all this increasing entropy plunge the universe into a state of total chaos if so it won't be the first time that the fate of the universe has been discovered in a glass of scotch on the rocks and so the entropy principle helps us to understand not only the efficiency of steam engines but why liquids freeze at a certain temperature and solids melt at a certain temperature but there are some people who believe that it has an even more profound meaning they believe that the entropy pense principle defines the direction of the flow of time itself let me try to explain suppose it were possible to see a collision between two atoms you might see one atom come in like this and then go out like that and the other atom comes in collides with it and goes out in that direction now if you had a movie of that event you would not be able to tell whether the movie were running forwards or backwards because at the microscopic level the law of entropy doesn't apply and the laws of physics work equally well forwards and backwards according to the law of physics the laws of physics time doesn't have a definite direction at this level but suppose instead you were to see somebody drop a ball from a tower if you had a movie of that you'd be able to tell instantly whether it was running forwards or backwards because when it's running forwards the bounces of the ball gets smaller each time it bounces if you saw the bounce is getting bigger and bigger you would know immediately that the film was running backwards now what's happening in that case is that the energy of the ball is turning into heat and that increases the enter be of the universe and you know without anybody having to tell you that the correct way to run the film is in the direction of increasing entropy and so that defines the direction of the flow of time and so there are some people who think that the second law of thermodynamics defines the direction of the flow of time there are others who say that the second law is a mere tautology entropy increases with time time increases with entropy so what else is new well I don't feel that way I think I understand perfectly which way time flows and I think I know that our time is up so I'll see you next time or if entropy should decrease I'll see you last time [Applause] thank you again Annenberg media for information about this and other Annenberg media programs call 1-800 lerner and visit us at WWE