The Thermodynamics Of Cooking And How Different Cooking Methods Work

"Thinkers get headaches. Worriers get ulcers." *Meathead*

By ***Meathead***

You may have thought you left physics and chemistry behind when you left school, but if you want to eat well, you need to understand that cooking is all about physics and chemistry, with a little magic mixed in. Here are some foundation concepts every outdoor cook needs to know.

What is cooking?

The definition of cooking. Most foods are composed mainly of water, fat, protein, and carbohydrates. Cooking is the process of transferring energy, usually heat, from an energy source to the food long enough to change its chemistry until you achieve safety and digestibility, as well as the desired flavor, texture, tenderness, juiciness, appearance, and nutrition.

The five ways heat cooks food. Food gets hot when molecules vibrate so fast that their temperature rises. Heat is transferred to food by means of *conduction, convection, radiation, excitation,* and *induction.* The processes have been described this way: Conduction is when your lover's body is pressed against yours. Convection is when your lover blows in your ear. Radiation is when you feel the heat of your lover's body under the covers without touching. Excitation is when she talks dirty to you on the phone. And induction is when she gives you electric socks.

Let's be a bit more precise:

Conduction is when heat is transferred to the food by direct contact with the heat source. Cooking a hot dog in a frying pan is conduction. Heat from the burner is transferred to the pan whose molecules vibrate, and pass the vibe on to the wiener. As the surface of frank gets hotter than the interior and the heat transfers to the center through the moisture and fats. That's also conduction. Grill marks on a grill are caused by conduction heating.

Convection is when heat is carried to the food by a fluid such as air, water, or oil. Cooking a hot dog in your kitchen oven where it is surrounded by hot air is convection. Cooking in a hot oven is a lot slower than in a frying pan because steel is 1000 times more dense than air which conducts heat at 1/30 the rate of steel. You can speed the process a bit by adding a fan to the oven and moving the air around as is done in a convection oven, but all ovens are really convection ovens. Boiling and deep frying are also convection cooking. Water is more dense than air and it holds more energy so it cooks faster, and oil faster still. The *interior* of the meat, however, is cooked by conduction as the heat travels through it.

Radiation is the transfer of heat by direct exposure to a source of light energy. Put a hot dog on a coat hangar and hold it over a campfire and you are cooking by radiation.

Excitation is how microwave ovens work. Microwaves are radio waves that penetrate the food and vibrate the molecules *inside* the hot dog until it gets hot without heating the air around it. Water in the food heats first in the microwave. Technically, this is a form of radiant heat cooking.

Induction is the latest technique for stove tops. An copper coil is placed under a smooth cooktop and an alternating current is sent through the coil creating a rapidly changing electromagnetic field. Electrons in conductive steel or cast iron pots placed above the electromagnet are jostled by the rapidly changing magnetism, but on each cycle lose a bit of energy due to electrical resistance, and the pot gets hot. The pot then transfers the heat to the food without the cooktop or the air around it getting hot. Induction is very responsive to the control knob and is extremely energy efficient, but it does not work with aluminum, glass, or copper pots.

The difference between heat and temperature and how all heat is not the same

If the concepts escape you, try this experiment (actually, don't actually*do* this but make believe you did). Put a pot of water in a 200°F oven for an hour. Open the door and stick your hand in the oven and count how long you can hold your hand in there. Perhaps a minute? Then plunge one hand in the 200°F water and place the other hand on the wire rack in the oven. After you get back from the hospital, ponder the fact that not everything that is 200°F cooks at the same rate. Because it is denser (it has more particles in a cubic inch), water contains more energy and transfers heat more efficiently than air, and metal faster still. That's why grill grates make grill marks even though they may be the same temp as the rest of the grill

According to the AmazingRibs.com science advisor, **Dr. Greg Blonder**, "Temperature measures the average energy of each atom. Heat is the total for all atoms. It's like money. If the average income in the US is $40,000 per family, the total wages are in the trillions."

Also, radiant heat has more energy than convection heat and delivers heat more effectively. Let's say you have two gas grills. On one grill, the two burners on the right side are on full and two burners on the left are turned off. The air temp on the left side, the indirect heat side, might be 325°F as convection flow of air from the right side circulates over the left side.

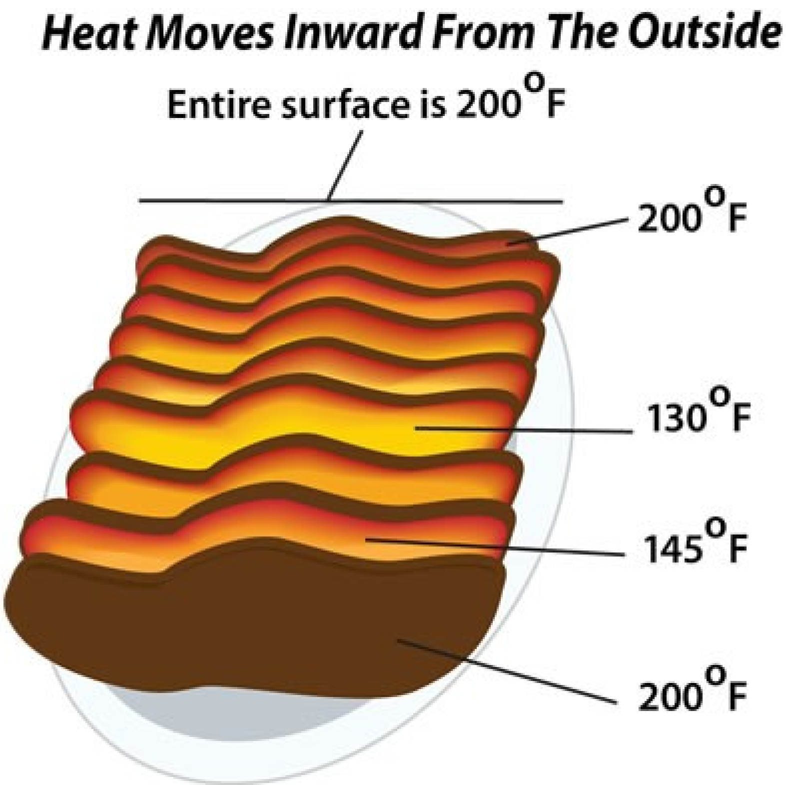
On the second grill you have all four burners on medium and the air temp on the both sides is also 325°F. A steak's surface will brown better on the left side of the second grill because it is above direct radiant heat which is imparting more energy than the first grill where the heat is from convection air. And it will brown darkest on the underside of the steak, the side facing the flame, not on the top side, because the bottom is being warmed by radiant heat and the top is being warmed by convection air that has less energy. Dark brown surfaces on steaks carry huge flavor bonuses.

The distance from the energy source is also an important factor. Energy dissipates as you move away from the heat source. In a $800 **grill made of ceramics** the heat source may be 2' from the cooking surface while on an $89 Weber Kettle the charcoal is only 4" away, and on a $30 Hibachi the coals may be as little as 1" away. The walls of a ceramic cooker are thick, they absorb huge amounts of heat, and then release it evenly making a very efficient oven with very steady cooking temps and very low fuel use. Perfect for roasting or low and slow cooking. But a steak on the cooking surface will not brown as well as on the Weber or even the Hibachi because the coals are so far away and because much of the heat comes from the ceramic side walls and dome, not glowing radiant hot coals right below the meat.

When is food ready to eat?

Food is ready to eat when it is safe and the target temperature is reached. A medium rare steak is 130 to 135°F in the center regardless of how thick, how much it weight, or what temperature it is cooked at. The single best way to tell if it is time to eat is with an accurate digital thermometer. You cannot tell by poking the meat unless you're a pro who has cooked the same steakson the same grill for years. **The single thing you can do to improve your cooking is to get a good digital instant read meat thermometer. The second most important thing you can do is get a good digital oven thermometer.**

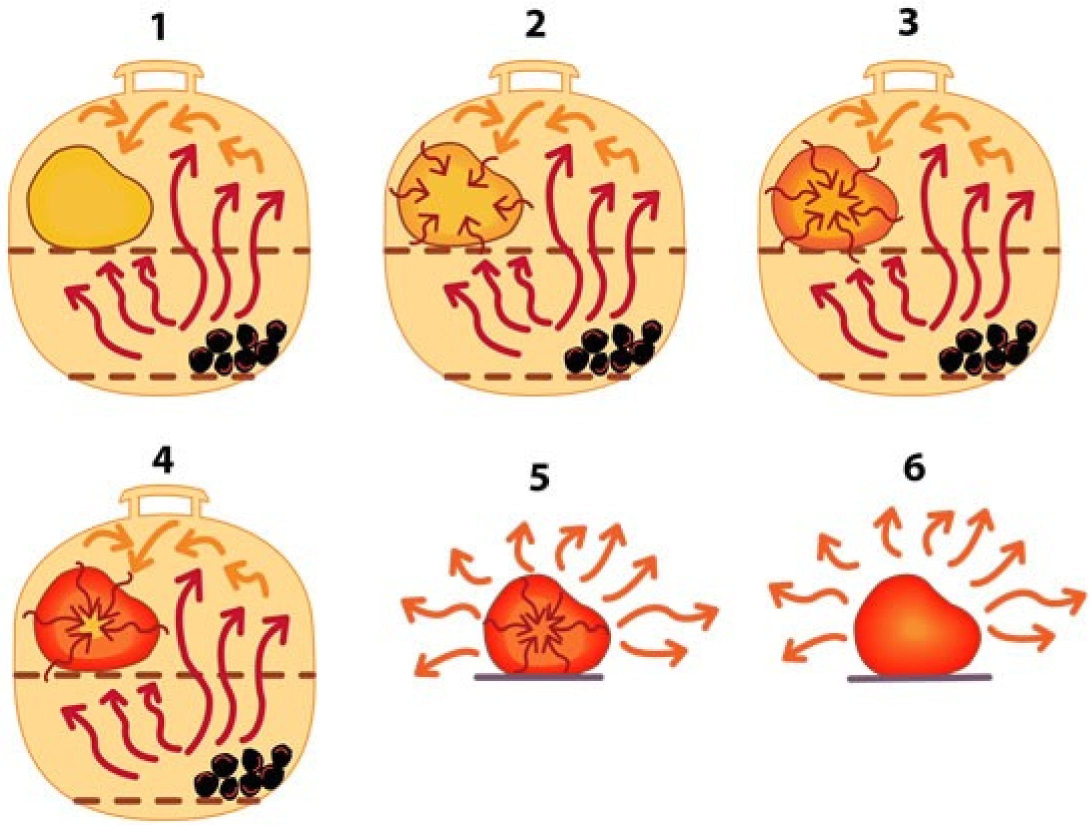
OK, some foods are hard to read with thermometers. You don't need a thermometer to tell when asparagus is ready, and because of all the bones it is almost impossible to tell when ribs are ready. But for most meats, there is no substitute for knowing precisely what temp the food is.



How heat moves within meat

The most important thing to understand is that when you put food in an enclosed vessel like a grill, smoker, or an oven, the hot air, which has lots of vibrating molecules, transfers some of its energy to the exterior of the meat. The energy in the air excites the molecules on the surface of the meat and then they transfer heat to the molecules inside it and so on, slowly passing the energy towards the center of the meat like a wave of heat. It takes time because meat is about 75% water, and water is a good insulator, especially when trapped inside muscle. The heat moves inward because physics dictates the the meat seeks equilibrium in an effort to make the temperature the same from edge to edge. So most of the meat is *cooked by the meat, not by the air*.

When you remove the meat from the heat, it continues to seek equilibrium and continues to cook because the heat built up in the outer layers of the meat continues to be passed down towards the center while some is escaping into the air and cooling the exterior. This phenomenon is called ***carryover cooking***.



A thick piece of meat such as a turkey breast might rise as much as 5°F in about 15 minutes after removing it from the grill because of carryover. A beef roast might rist 10°F. A thinner piece of meat such as a thick steak might only rise a couple of degrees, and chicken breast may not rise at all. This is important to know this because 5 to 10°F can make the difference between moist turkey and cardboard, a medium rare steak and a drier medium steak. To compensate, **use a good digital thermometer** and remove thick cuts of meat about 5°F below your target temp.

In the first frame of the illustration above you can see radiant heat rise from the coals and bouncing around the interior of the grill. The meat is set off to the side so it is not directly over the coals to prevent it from burning and to allow it to slowly roast in convection airflow (this is called a **2-zone setup** and is a foundation concept). In frames 2, 3, and 4, the heat warms the exterior of the meat and the meat passes the heat towards its center. In frames 5 and 6, the meat has been removed from the cooker and it starts to cool, but at the same time it continues to push heat towards the cooler center trying to equalize the temp in the meat.

Thickness is more important than weight

The temperature of your food moves slowly upward during cooking, but the thickness of the meat is a major factor in how long it takes to get the center to the desired temperature. A thin steak cooks faster than a thick steak. And a 5" thick prime rib that weighs 8 pounds will be done in the same time as a 5" thick prime rib that weighs 12 pounds. So any recipe that says "cook your steak for three minutes per side" without specifying the thickness of the steak, is seriously flawed. Likewise any recipe that says "cook your roast 30 minutes per pound" is suspect.

About boiling temps and how the impact cooking

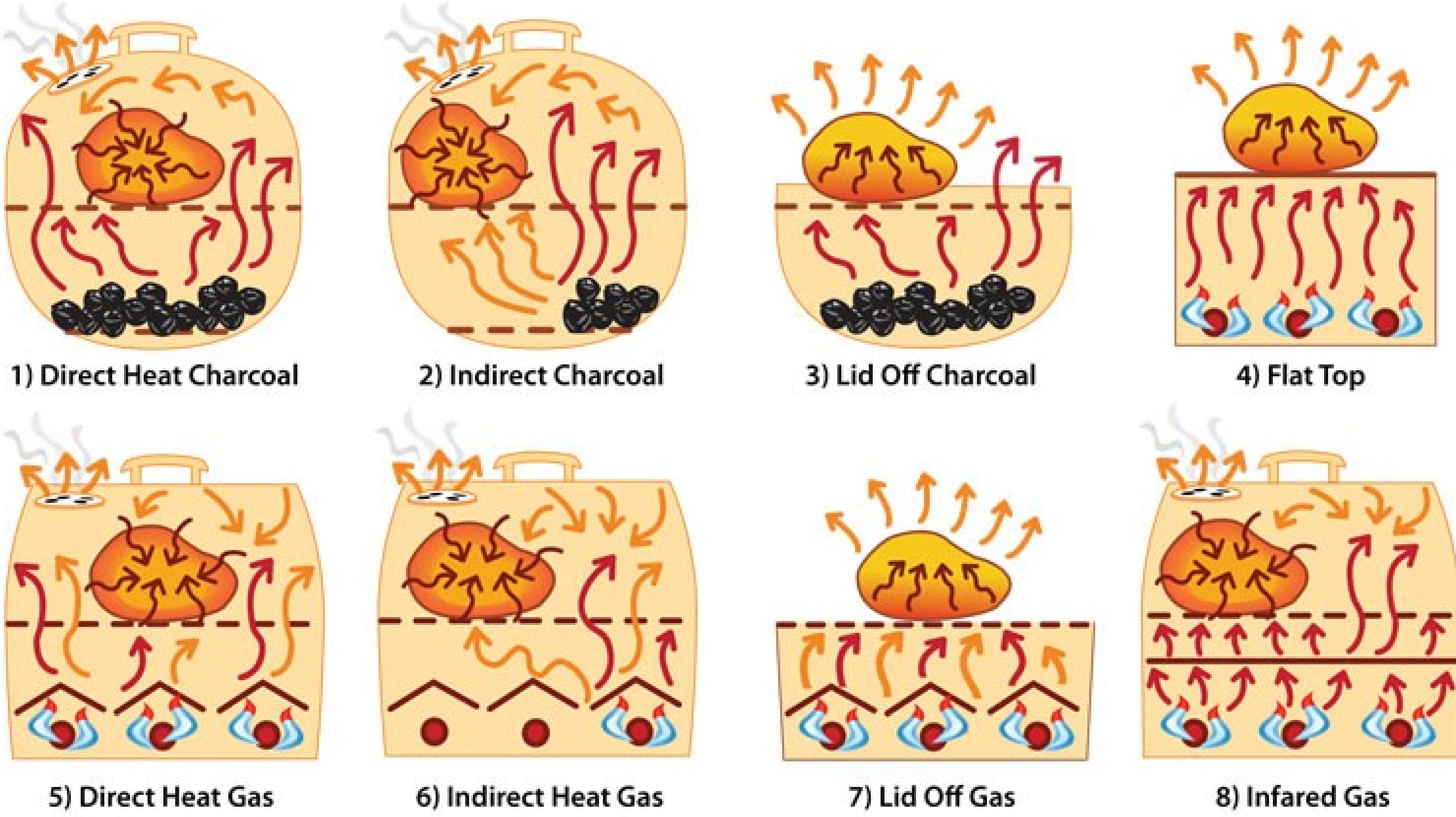
Another important concept to know is that when liquid is heated, its temp will increase until it hits its boiling temp and not go any higher. So no matter how high you turn up the burners under a pot of water, the water will not get hotter than 212°F. If you have a sauce made of wine and olive oil it will heat to the boiling temp of alcohol, about 172°F, and hold there until all the alcohol is boiled off, and then rise to the boiling temp of water (wine is mostly water), 212°F, until all the water boils off, and then rise to the boiling temp of the oil, about 572°F.

Interestingly, steam can be hotter than 212°F, but food submerged in boiling water will cook faster than food bathed in steam because the food's surface is completely surrounded by hot water molecules.

This also applies to wood chips. If you soak them in water, first of all they won't absorb much (that's why boats are built from wood). But when you toss them on the coals, the wood stays a cool 212F until the water boils off. It cannot smolder until it hits a much higher temp, so soaking wood chips so they will smolder better is just another old husband's tale. **Click here to read more on soaking wood**.

How your grills work

The illustration below shows how different outdoor cookers work.



1) Direct Heat Charcoal. Charcoal produces radiant heat in the fire box. The grates absorb heat and produce conduction heat on surface of the food. The exterior of the food absorbs direct heat from below. The lid reflects mostly convection heat. The exterior of the food produces conduction heat and it moves to the center of the food.

2) Indirect Charcoal. Charcoal produces both convection and radiant heat in the fire box. The grates absorb heat and produce conduction heat on surface of the food. The exterior of the food absorbs indirect convection from all sides. The lid reflects mostly convection heat. The exterior of the food produces conduction heat and it moves to the center of the food.

3) Lid Off Charcoal. Charcoal produces radiant heat in the fire box. The grates absorb heat and produce conduction heat on surface of the food. The exterior of the food absorbs radiant heat from below only. The exterior of the food produces conduction heat and it moves to the top of the food. Without a lid, radiant heat escapes from the food upward, cooling its top.

4) Flat Top. Gas produces both radiant heat in the fire box. Solid griddle under the food absorbs heat and produces conduction heat on surface of the food. The bottom of the food absorbs conduction heat and produces conduction heat moving to the top of the food. Without a lid, radiant heat escapes from the food upward, cooling its top.

5) Direct Heat Gas. Burners produce radiant heat which heats metal drip protector bars, lava rocks, or ceramic briquets. They absorb heat and produce radiant and convection heat. The grates absorb heat and produce conduction heat on surface of the food. The lid reflects mostly convection heat. The exterior of the food produces conduction heat and it moves to the center of the food.

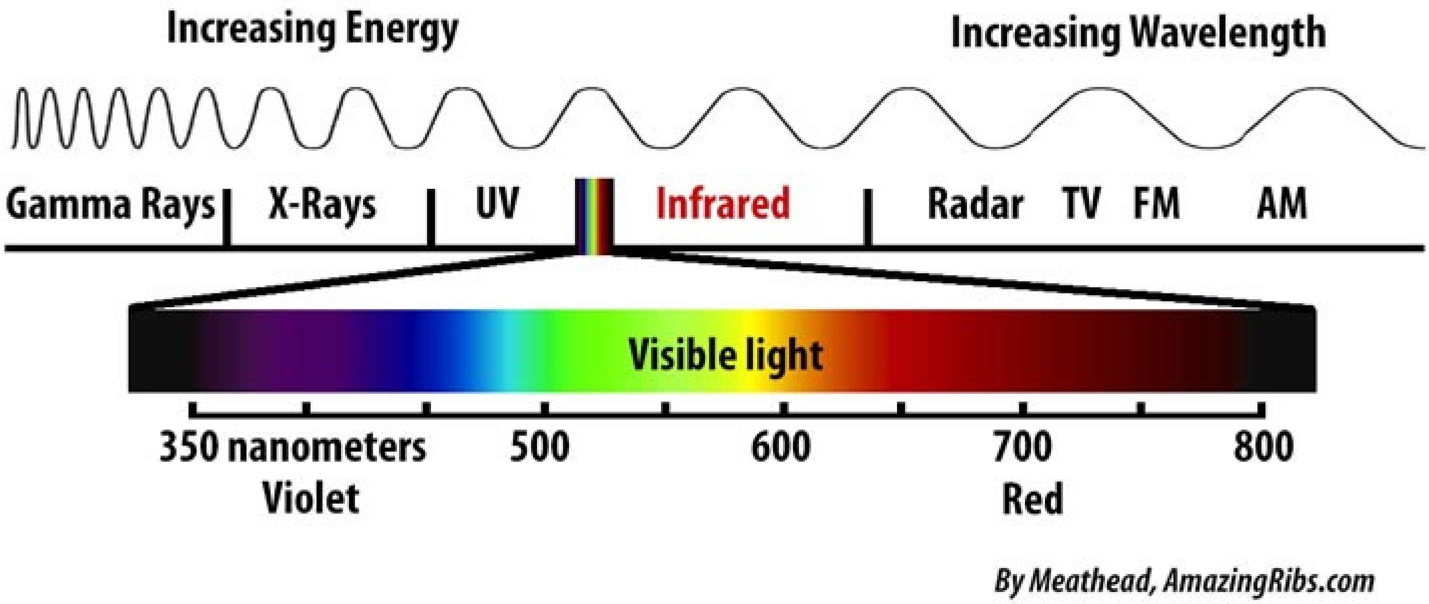
6) Indirect Heat Gas. Burners produce radiant heat which heats metal drip protector bars, lava rocks, or ceramic briquets. They absorb heat and produce radiant and convection heat. The grates absorb heat and produce conduction heat on surface of the food. The lid reflects mostly convection heat. The exterior of the food absorbs indirect convection from all sides. The exterior of the food produces conduction heat and it moves to the center of the food.

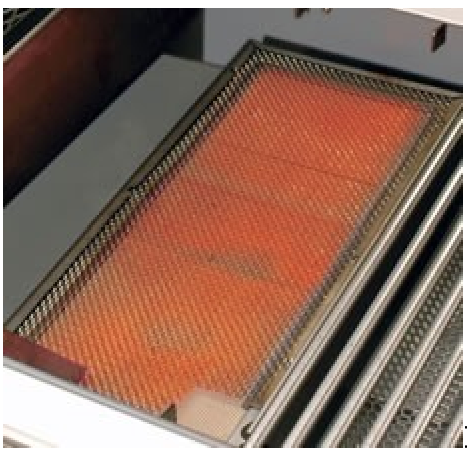
7) Lid Off Gas. Burners produce radiant heat which heats metal drip protector bars, lava rocks, or ceramic briquets. They absorb heat and produce radiant and convection heat. The grates absorb heat and produce conduction heat on surface of the food. The exterior of the food produces conduction heat and it moves to the top of the food. Without a lid, radiant heat escapes from the food upward, cooling its top.

8) Infrared Gas. Burners produce radiant heat which in turn heat a special plate. It absorbs heat and emits it as radiant heat in the infrared part of the spectrum. Grates absorb heat and produce conduction heat where it contacts the surface of the food. The exterior of the food absorbs heat and produces conduction heat moving to the center of the food. The lid reflects both radiant and convection heat.

What's all the fuss over infrared?

In the past few years a number of gas grills have been touting their superiority because they use "infrared" (IR) heat or they have an IR "sear burner" designed to generate high heat for getting a dark sear on steaks. If you remember your high school science, you know that infrared is a section of the wavelength continuum around us, just down the road from visible light and up the road from the radio in your car.



Infrared is a form of radiant heat. In an IR grill a plate of special glass, ceramics, or metal, sits above gas burners and below the cooking grate. The plate absorbs the heat and light from the flame and re-radiates it to the food in the form of invisible infrared light rather than warm convection air as do most gas grills. About 2/3 of the heat is IR and the rest is conventional convection heat which is much less intense than IR. Convection heat can be dissipated easily by air currents and short distances while IR gets through.

Dr. Greg Blonder, our science advisor explains: "If you warm a plate of steel or special glass or ceramic, the atoms in the plate begin to oscillate. At low temps almost all of the energy is stored as vibrations in the plate. As the plate heats up, the rapidly vibrating atoms cause it to emit IR. Think of it (very loosely) like a bowl of gasoline in a room. At low temps most of the energy is confined to the liquid. At higher temps there is so much vibration that the gasoline evaporates."

Max Good, our director of product reviews elaborates: "All IR heat is radiant, but not all radiant heat is IR. IR waves move very fast through the air. The sun radiates intense IR waves which travel great distances at the speed of light without dissipating until they contact solid matter, like your skin, which it warms. The sun also radiates other waves, like ultraviolet (UV), which cause sunburn as well as heat."

As another example Good says "Consider the IR heaters in warehouses. They are often suspended from the ceiling, but one can easily feel the heat waves standing beneath them. If these same devices were simply conventional gas burners, most of the heat would rise upward."

Blonder adds "An oven set on broil is also a radiant heater, with much of the heat is in the *near* IR, the almost visible section of IR. In principle, a pure IR heater would not be visible to the naked eye, since our eyes can't respond that far out in the light spectrum. In practice, an IR heater glows a dull red, as opposed to a bright red broiler or white hot coals. But they are all radiant heaters."

Is IR heating better? Blonder says "IR energy is delivered faster than convection, but slower than conduction. So it can brown a little more effectively than a conventional grill but not as fast as a hot pan or grill grates. There are fewer hot spots from IR cookers. On the other hand, you can get 'thermal runaway' with IR. If one section of the meat is dark, it absorbs more IR than the lighter sections. Thus browning, and becoming darker still, eventually burning." And real IR burners are not good at achieving low temperatures.

We recommend them for getting hot sears on steaks and other meats when the browning of the surface creates thousands of new flavor compounds.

Master of the flame and keeper of time

Good cooking is the proper combination of heat and time. The higher the heat, the less time needed. Lower the heat, you need more time.

But you just can't set your cooker for Warp 10 on every food. Some demand low and slow. **Read more about cooking temperatures here**.

Your indoor oven has three basic components to control heat and time: A heat source, a thermostat, and a timer. Your outdoor oven, and an oven is exactly what your grill or smoker is, has a heat source, but only a few have a thermostat or a timer. And that's why cooking outdoors is much more difficult indoors. Tell that to your significant other (and sleep on the couch).

To make good food outdoors you need to become master of the flame and keeper of time. Many grills come with a thermometer, but they are usually crap. The thermometer on my gas grill is often off by 50°F! You absolutely positively must have a good oven thermometer.

In addition to knowing what temp your cooker is, you need to know what temperature your meat is. Cooking without a meat thermometer is like driving without a speedometer. You might think you're under the limit, but try explaining that to the judge. You might think the meat is ready, but try explaining that to your guests when it is dry enough that they ask for a glass of saliva to help them swallow. Here is **a meat temperature guide**, and here's **everything you need to know about thermometers** with links to good ones you can buy.

Some of the better digital thermometers have timers. If yours does not, get in the habit of wearing a watch when you cook and write down what time you put the meat into the heat in **a cooking log**. Some of the old timey barbecue artisans say you can learn to cook by sight, smell, and feel. That's just plain BS. Once you know how to cook you can rely more and more on your senses, but until you are ready to call yourself a top chef, get a thermometer, wear a watch, and keep a log. I do.