**3. Heat (Thermal Energy) (Physical Sciences)**

Heat moves in a predictable flow from warmer objects to cooler objects until all the objects are at the same temperature. As a basis for understanding this concept:

a. Students know energy can be carried from one place to another by heat flow or by waves, including water, light and sound waves, or by moving objects.

b. Students know that when fuel is consumed, most of the energy released becomes heat energy.

c. Students know heat flows in solids by conduction (which involves no flow of matter) and in fluids by conduction and by convection (which involves flow of matter).

d. Students know heat energy is also transferred between objects by radiation (radiation can travel through space).

Hello again my dear Friends in California,

My first two letters to you were about how the surface of our Earth is shaped. We talked about how continents move around, pushing up mountain ranges and making earthquakes, etc. We talked about how water makes valleys and creates rich farmland and beaches and so much else.

This letter and the next will talk about energy. Especially heat energy because heat is the most important form of energy for life. Too much of it, you burn to death. Too little and you freeze to death.

So today I want to get you asking questions about heat.

We all need control over the heat. Don't you feel too hot sometimes? Or too cold? Don't you do something about it? ... And it's not just us human beings. Oh no. All of life is threatened by too much heat, or too little. We all need our heat somewhere in the middle. Everywhere you look in nature there are creatures adapting to the temperature.

Mammals have fur and birds have feathers to insulate against the cold. Insects hatch in the spring when it's warm enough to survive. Plants flower when there are insects to pollinate them. Leaves catch the energy of the sun and turn it into fruits and seeds and broccoli and carrots. Everywhere are these amazing inter-relationships between creatures and their environments and so many of them have something to do with heat.

But what is heat? We all know it when we feel it. We all know how we feel when we shiver in the cold. We all know what we do when we burn our hand on a hot stove. We all know how nice it is to have a warm shower on a cold day, or a cool swim on a hot one.

The rising sun on a cold morning falls on our skin and what do we feel? Yes, you got it. We step into the shade of a tree on a hot afternoon and... oh, what a relief.

We all know what it feels like to “have a temperature” when we are sick.

But how are we to connect all these feelings of heat with our knowledge of the world we share?

There are three questions here:

What is the nature of the heat we feel?

How does heat move from one place to another?

How is heat created out of matter?

We'll take these up one at a time.

What is the nature of the heat we feel: As you must know, every substance in the world is made out of atoms. And most of the atoms are assembled into molecules. For example, water is a molecule made of two hydrogen atoms and one atom of the oxygen I discovered. And every atom in every molecule in this universe is in constant motion. Forever bouncing off its neighbors, so to speak. If the substance gets hotter, the atoms are moving faster. If it gets cooler, the atoms are moving slower. The temperature of a substance is nothing more—and nothing less—than a measure of how fast its atoms are moving.

Take water for example. When water is in the form of ice, the molecules are holding each other in a rigid framework that makes the water solid. The atoms in the molecules are moving slowly. They just sort of wobble in place, and when they bump one another they don't knock each other out of formation.

But if you put the block of ice onto something warm, say a piece of warm iron, the faster moving atoms of iron bump into the slow molecules of water in the ice and they get the ice molecules all excited. The ice molecules start moving faster and pretty soon they shake the framework apart. This is the melting of the ice. The molecules are no longer held in a rigid structure but are much more loosely tied together, something like a billion strings of horses, which can flow through each other. This is water in its liquid state in which the molecules are moving faster than when it was ice.

In the same way, if you put your hand on a hot piece of iron, your hand gets hot because the hot molecules of iron bang into the molecules that make up your skin and get them moving fast too. Your hand could get cooked! Fortunately, we have evolved millions of tiny sensors in our skin. They know when their molecules are moving too fast and scream out to the brain, “Hey, get me out of here.” And a message quick-as-a-wink comes to the muscles to pull that hand away from that dangerous heat.

And the opposite happens too: if you touch ice, the molecules of your hand heat up the ice. But in so doing, they lose some of their energy and slow down. Your hand gets cold. And a different set of sensors in your skin set off their alarm that the hand is getting too cold.

So our skin is continually sending messages to our brain about the temperature of every solid, every liquid, and every gas that comes in contact with it.

But what about the heat we feel directly from the sun? That heat has to travel through empty space more than ninety million miles to reach your skin on a cold winter day. There's no material, no substance traveling through that space. The light and heat travel in the form of waves, and when those waves strike matter their energy is transferred to the matter, or else reflected off it. This is called radiant energy. So when the sun's heat waves strike your skin some of their energy is absorbed by the skin and the skin molecules start to move faster, just as if some hot liquid was flowing over it. And you feel the warmth.

So we can answer our first question: What is the nature of the heat we feel?

It is the heat of our skin's molecules vibrating with a faster movement and that speed being sensed by tiny sensors in our skin.

Our second question was: how does heat move from one place to another?

We've already talked about two ways that heat can move. When we touch hot iron or ice the heat moves directly from the hotter object to the cooler one. The molecules of the hotter object slow down. Those of the cooler object speed up. The temperature of both of them settles down, somewhere in the middle. This movement of heat is called **conduction**.

Of course your skin doesn't have to be involved in conduction. If you put a cool frying pan onto a burner, the bottom surface of the pan quickly conducts heat to the upper side. In just a few minutes you have your egg, sunny side up.

But the sun in the sky does not use conduction to get its heat to the earth. The heat waves we talked about are called **radiation**. The sun continually radiates light and heat and other forms of radiation that are all falling continuously on the earth. All this energy is either absorbed, or else it's reflected to fall on other objects. Some things absorb more and reflect less.

You see striking examples of this every winter. When the sun shines on an asphalt road, a lot of the radiant heat is absorbed and held by the asphalt in the form of molecular heat. The asphalt road stays warmer than the ground on either side. When the snow starts to fall, it all melts on the asphalt, even as it builds up beside the road.

But it is not only the sun that gives off radiant energy. When your frying pan got hot, it not only conducted energy to the egg, it also radiated energy into the room. That's why wood stoves work so well. That hot iron is radiating energy to everything in sight of it and warming all those objects up.

So two of the ways that heat moves around are **conduction** and **radiation**. Are there more?

Well of course there are. You've done it yourself. You take a cup of hot chocolate from the kitchen to the couch and you've moved heat around. You turn on the hot water faucet and heat moves from the water heater to the sink or the bathtub. If a bear goes into a cave to hibernate, it brings the heat of its body into the cave.

But are there ways of moving heat around—without the help of living things—that are neither conduction nor radiation?

The warm winds of summer are moving heat around—as are the cold winds of winter. There are the rivers in the ocean that move around almost unbelievable amounts of water making some countries colder and some warmer. There are eruptions of volcanoes and the spewing of geysers that bring heat up from the center of the earth. All of these are examples of what we call convection.

Convection happens right in your own home. If you turn on a gas flame on your stove the flame itself releases radiant heat but also a whole lot of fast-moving molecules which conduct heat to the surrounding air. That hot air expands and becomes lighter. The lighter air rises and more cooler air is sucked in toward the flame where its oxygen burns and makes more hot air that rises. This rising air sets little currents in motion which carry the warm air throughout the space. It mixes with the cooler air. Gradually the whole room gets warm.

So the three main ways that heat moves around are **conduction** – when things touch each other, **convection** – when air or liquid or magma under the earth flow from one place to another, and **radiation** – when waves of energy are radiated by one substance and absorbed by another.

So that's an introduction to the nature of heat. In the next letter we'll look at how heat works on our home planet.

Yours in the spirit of inquiry,
Joseph Priestley