7. Energy

Energy Units

In previous chapters we have been quite particular to make things as precise as possible. Distinguishing between mass and weight, and between speed and velocity for example. It is much harder to be precise about *energy.* So in this essay there are examples of different forms of energy and how they may change form. In this way we hope that eventually the wood may become visible from the trees.

A simple consumer definition of energy might be that it is something you have to pay for: electricity, gas, oil, petrol, food – stuff you can do something with. The thing that these have in common is that they can all end up producing heat – and electric fire, a gas boiler, petrol burning in the engine of a car, and food producing heat in the body to keep warm. Electricity, in particular, can do other things as well. For example it can work motors in a washing machine, it can light LED lights and operate a TV.

The energy that these can produce is measurable, but there is no easy unifying unit that is used generally. Let's look at these in turn.

Think about electrical equipment in the house that contain motors. A washing machine has a fairly powerful motor whilst the motor in a fridge can be smaller and much less powerful. The power is measured in units call watts (W). Similarly electric heaters may have a variety of powers. A typical convector heater may have a power of 2000 watts. A gas boiler used for heating a home will have a larger power maybe 30,000 watts. Because these numbers are quite large it is usual to use kilowatts where 1 kilowatt (kW) is just 1000 W.

What is your 2000 W convector heating doing? It is taking 2000 units of energy every second from the electricity supply and turning this into 2000 units of energy as heat. We need a name for the unit of energy. The basic scientific unit of energy is the joule (J) in honour of an English physicist James Prescott Joule (1818-1889) who established that there were various forms of energy that could be changed, one form to another. A joule is a unit *of energy*. So our 2 kW convector fire takes 2000 joules of electrical energy every second and turns this into heat. So after 2 seconds we have 4000 joules of heat energy in the room, after 3 seconds 6000 joules of heat energy and so on.

So the number "2 kW" stamped on the fire tells us the rate at which our convector will convert electrical energy into heat – 2000 joules every second. **One watt is just shorthand for 1 joule per second.**

Electrical energy is paid for in "units". The unit is the kilowatt-hour. This is the energy used by a 1 kilowatt appliance running for one hour. To get the number of units an appliance uses you multiple the power in kW by the number of hours it is left on. A common household appliance is a 2 kW (kilowatt) convector heater. In one hour this will use 2 kWh (kilowatt hours) i.e. 2 units. The electricity supplier will quote how much each unit costs so you can work out the cost of running the appliance for 5 hours, say.

Already here there are seeds for confusion. We have kW and kWh. kW measure ***power.*** This is the ***rate*** at which the machine can use energy. On its own it tells you nothing about what your electricity bill will be. To get the ***energy*** you use it is necessary to multiply the power of the appliance in kW by the number of hours it is on for. This gives you the energy in kilowatt-hours kWh. Obviously you will need to add this up for all the appliances used.

So there is the distinction between the POWER of an appliance measure in kW and the ENERGY it uses measure in kWh (which you get by multiplying its power by the number of hours).

****** BOB INTERRUPTS ******

Bob: I get confused. What people say on the TV seems to be different. Can Alice explain?

Alice: You are right Bob. Often people use kW when they mean kWh. Just the other say an announcer was saying how much energy had been generated using fossil fuels and how much using renewables. They used kW when they meant kWh. This does not help people understand.

Bob: So to get this straight a power stion might be generating energy at a certain rate and it would be OK to quote kW for the. But the total energy generated should be in kWh.

Alice: Exactly right. Your 2 kW electric fire uses no energy when it is not plugged. The energy used when it is plugged in depends on its power in kW and the number of hours it is on for. You can feel superior when you spot the mistakes on the TV.

Gas used to be uniformly measured in the number of cubic metres volume used. Nowadays the gas board will know how much energy is produced for each cubic meter burned so for ease of comparison they will also quote the use in kWh. This also makes sense as domestic boilers will have the maximum rate of energy they can produce measured in kW.

To summarise.

ENERGY UNITS

- 1 joule is the basic unit of energy
- 1 kWh is a more practical unit of energy for households. It is the energy used by an appliance with a 1 kW power rating running for 1 hour.

POWER UNITS – Power is energy used per second

- 1 watt is a unit of power – energy used **per second**, i.e. **1 watt is 1 joule per second**
- 1 kW is a larger unit of power equal to 1000 W.

Since a joule and a kWh are both units of energy we ought be able to work out how many joules are equivalent to 1 kWh. 1 kWh is the energy used by 1 kW for 1 hour. This is 1000 joules per second for 1 hour. There are 3,600 seconds in one hour so 1 kWh = 1000 J per second for 3,600 seconds. This is 3,600,000 J. This is 3.6 million joules written as 3.6 MJ.

So 1 kWh = 3.6 MJ.

What about oil for heating when there is no suitable electric or gas available? Oil is sold in litres. I.e. it is sold by volume. But the vendor should also be able to supply the energy that each litre of oil will produce. Typically 1 litre of heating oil will provide 36 MJ. Since 1 kWh is equivalent to 3.6 MJ then 1 litre of oil will provide 10 kWh. The energy per litre is not fixed and will fluctuate somewhat depending on the origin of the oil.

At least up to now we have just two units of energy the J (or more usefully the MJ or kJ) and the kWh. However there is food to throw into the mix. Not so long ago it was hard spot a food label where the energy content was stated in J. It was almost universally in calories. And to add to the confusion when calories were quoted they often meant kilocalories (1000 calories). Looking at food labels in the kitchen today most are labelled correctly with both units kJ (1000 J) and kcal (1000 calories).

Where does the calorie come from? It has a precise scientific definition. It is the heat required to raise the temperature of 1 gram of water by 1 °C. It is quite a small unit of energy, as it the joule. It turns out that 1 calorie is equivalent to 4.2 joules. On food the values are quoted per gram or per 100 gram or per serving and generally in kJ and kcalories. The number of kJ will always be 4.2 times the value of kcalories.

The way the body uses energy is biologically complex, but most of the energy that is consumed from food end up as heat, we need to keep warm and we get hotter when we exercise. (This is really too simplistic). Any food not used in this way is likely to contribute to weight increase. For men the average requirement per day is about 2,500 kcalories = 2.5 Mcalories = 10,500 kJ = 10.5 MJ. For women the average is about 2,000 kcalories = 2 Mcalories = 8,400 kJ = 8.4 MJ.

If you feel so inclined you can divide the MJ by 3.6 and so men need 2.9 kWh and women 2.3 kWh. So the equivalent of running our 2 kW convector heater for between roughly 1 to 1.5 hours.

Forms of Energy

Mostly the energy we buy in the form of gas, oil and food gets "burned" and turns to *heat*. Heat is a form of energy. As was mentioned above the calorie is defined as the heat needed to heat up 1 gram of water by 1 °C. James Prescott Joule asserted that energy can be transformed from one form to another. If we end up with heat when gas is burned, where is the energy to start with. The answer is that it is stored *chemically* within the molecules of the gas. When the gas is burned this chemical energy is released in the form of heat. In itself this is simple enough, but the actual processes of how the energy is chemically stored, and how it is released, are far from simple.

Objects moving possess energy. It is called *kinetic energy*. You can't get something moving for nothing so it is reasonable to suppose that this movement possesses energy. To operate a motor in a washing machine it needs a supply of electrical energy. The motor will have its power in watts somewhere stamped on it. To stop a car moving you need to apply the brakes. This causes the brake pads to rub on the discs and the friction produces heat. The kinetic energy of the car has been changed into heat – which in this case is fairly useless. Electric cars fare better in that they can use "regenerative" braking. When you take you foot off the accelerator the car motors act in reverse and produce electricity which is used to help recharge the battery.

Now think of a pile driver being driven into the ground to support some structure, maybe a pier at the seaside. A heavy weight is hauled up and then let drop onto the pile at some speed. This exerts a big force on the pile hopefully forcing it into the ground. Clearly when the weight hits the pile it has a lot of kinetic energy. But where has this come from? Motors will have to have used energy to haul the weight up. But the weight at the top is not moving. It appears to have no energy. Yet as it falls it gains kinetic energy. The explanation is that in lifting the weight upwards against the pull of gravity it has been given *potential energy*. As the weight falls this potential energy is turned into kinetic energy.

In fact this idea is used to define a joule. It is the energy need to move an object 1 metre when opposed by a force of 1 newton. So to move 2 m would need 2 J, and if the force was 3 N for 2 m the energy would be 6 J. The mass of the pile driver might be say 150 kg. We have said before that on the earth the weight on a 1 kg mass is very nearly 10 N. So our pile driver has a weight of 1,500 N approximately. If it is lifted 3 m the potential energy stored would be 4,500 J which would be converted to kinetic energy as it falls.

Other forms of energy include light, sound, and nuclear. All these forms can change from one form to another depending on the circumstance.

Summary and Looking Forward.

We have energy in different forms that can change from one form to another:

Electrical
Chemical
Heat
Kinetic
Potential
Light
Sound
Nuclear

And we have a plethora of units for measuring the amount of energy.

You would be forgiven for thinking this is a bit of a mess. It would be great from a scientific point of view if we could always use the joule for energy measurement. But history and convenience denies this.

And all these forms of energy swapping and changing can be confusing. It arises from a need to communicate ideas at a not too difficult level. In fact there are really only two forms of energy *kinetic* and *potential*. But it is hard to see this until everything is looked at in a more detailed level. Some of this we will do later.

The big fundamental rule we have not yet mentioned that is that when energy is swapped around the total amount of energy stays the same. **This is “The conservation of Energy” a fundamental law of Physics.**