PHYSICS

Electric Power and Magnetism Report

1. What is a magnetic field? Give examples of different magnetic fields.

A magnetic field is the area or region around a magnet where magnetic forces can be felt. If a piece of magnetic material such as iron is placed within this area, the field causes the material to experience a force. The strength of a magnetic field varies around a magnet.

Magnetic Field Strength (**B**) or **Magnetic Flux Density** is a vector quantity. That is, it must have a magnitude and direction. It is measured in **Tesla** (**T**). The imaginary continuous lines drawn around a magnet in diagrams represent the direction of the magnetic field (a tangent line drawn at any point along the continuous lines is the direction at that point) and their closeness, the strength of the magnetic field at that point. These are generally called **Lines of Force** or **Magnetic Field Lines**.

Any magnet is composed of two significant ends called **Poles**. We call these ends the **North Pole** (or **North Seeking Pole**) and the **South Pole** (or **South Seeking Pole**). These two poles are always found in combination on any magnet. We call this combination a **Dipole**. The direction of the magnetic field is ALWAYS from North to South. That is, the North Pole, to the South Pole. As a rule, opposing poles (Example: NS and SN) attract towards one another and like poles repel one another (Example: NN and SS).

Magnets can be designed so they produce fields of different shapes: Examples include a small bar or block magnet, a horseshow magnet or a circular magnet.

2. How is magnetic field strength measured and in what units? Give some typical examples of magnetic field strength.

How is a magnetic field strength measured and in what units? Give some typical values of magnetic field strength.

Tesla (T) is the SI unit used to measure Magnetic Field Strength (B) or "Magnetic Flux Density". 1 tesla is equal to 1 Weber per meter squared (Weber (Wb) being the SI unit used to measure Magnetic Flux).

$$1\,\mathrm{T} = 1\,\frac{\mathrm{V \cdot s}}{\mathrm{m^2}} = 1\,\frac{\mathrm{N}}{\mathrm{A \cdot m}} = 1\,\frac{\mathrm{Wb}}{\mathrm{m^2}} = 1\,\frac{\mathrm{kg}}{\mathrm{C \cdot s}} = 1\,\frac{\mathrm{kg}}{\mathrm{A \cdot s^2}}$$

A = amperes
C = coulombs
kg = kilograms
m = meters
N = newtons
s = seconds
T = teslas
V = Volts
Wb = webers

Magnets and magnetic fields have different field strengths than others.

- Earth has a miniscule magnetic field strength of 0.1 mT (millitesla)
- A typical magnet from a refrigerator is about 5 mT to 30 mT
- A typical magnet from a school science lab is about 0.6 T
- The strongest (permanent) magnetic fields in existence, used for science, have strengths of about 10 T
- The strongest (pulsed) magnetic field ever obtained in a scientific laboratory (with explosives) was 2.6 kT (kilotesla)
- The strength of a magnetar (A Neutron Star with an extremely powerful magnetic field) ranges from 0.1 to 100 GT (Gigatesla)

3. **What is an electromagnet, how do they work (principle) and where are they used?**

An electromagnet is a temporary magnet created by coiling wire around an iron core. When current runs through the wire the iron becomes magnetized, creating a temporary magnet. Therefore, an electromagnet runs on electrical current; that is electricity.

If a piece of iron is placed within a magnetic field, then via induction, the iron becomes magnetized as a temporary magnet. If we take this concept further, and this time put the piece of iron within a coil of wire or a solenoid; when the current it turned on and allowed to flow through the wire/solenoid and around the iron core, the field of the current induces magnetism in the iron. This makes the total magnetic field much stronger than if it were just the current and solenoid alone. The magnetic field strength increases to the point where it can support more than its own weight (the combined weight of the solenoid and iron core). The result is an electromagnet – a magnet that can be turned on and off by a switch!

An electromagnet is made stronger by increasing the current through the solenoid/loop of wire(s). When the current it lost or turned off, the electromagnet will slowly (not immediately) lose its magnetism. A permanent magnet can be created by adding Carbon to the iron core to produce an alloy.

Common uses for electromagnets include DC Motors, loudspeakers and headphones (to drive the diaphragm), televisions (to drive the electron beam on the screen) and in scrap/junk yards/factories or construction sites to pick up and lift heavy and large amounts of metal. (Example: in a junk yard to lift the masses of wreaked cars)

4. **What is the "Right Hand Slap Rule"? Explain how this is used by making up your own worked example.**

The right hand slap rule is a 'Physical Rule' that is executed with a person's right hand. We use this rule to help us determine the directions of the force and magnetic field in a current carrying wire. The key terms/variables that are used in this rule are: **Force (F), Magnetic Field Strength (B) and Current (I).**

To form the Right Hand Slap Rule with your right hand, you essentially pretend to slap yourself on the cheek. You use an open (flat) hand with your 4 primary fingers extended together and your thumb cocked at a right angle to them. Your extended fingers represent the direction of the magnetic field (B). Your thumb is in the direction of the current (I) flowing through the wire. The direction of the force (F) extends in a straight line, perpendicular from the center of your palm.

It is important to note that the Force, Magnetic Field and Current are all at right angles (90^o) to each other when using this rule. When talking about magnetism, if the magnetic field and current are at right angles to each other (as is the case here), then the force that results will be maximum. If the angle between the magnetic field and the current is less than 90^o the force that results will be smaller. An angle of zero results in zero force acting as the magnetic field and current are now parallel to each other.

5. **A fast moving electron in a TV tube will deflect when it is in a magnetic field. Explain how this works. Use a diagram to help with your explanation.**

When any charge such as an electron moves across a magnetic field, it experiences a sideways force that deflects the motion of the charge (in this case, the electron). The electron now moves in a different direction, but is still at right angles to the magnetic field (the strength of the resultant force remains unchanged). The direction of the force will always be perpendicular to the electron and its velocity, resulting in its constant deflection each time. This results in the electron travelling in a circle or arc (as it is deflected more and more).

Note: Because the force is always at right angles to the electron, it can only alter its direction NOT its speed (Circular motion). We can use the Right Hand Slap rule to determine the direction of the resultant magnetic force on the electron.

The size of force (F) acting on any charge (Q) moving at a speed (v) through a magnetic field (B) can be obtained from the equation (derived from $F = nBIL$):

$$F = BQv$$

6. What is the equation for the force acting on a moving charge in a magnetic field? State this with an explanation of units and make up your own worked example using this equation.

When a current carrying wire is placed into a magnetic field of certain strength, there will be a force created that acts on the wire. The magnitude of this force is proportional to the size of the current (I), the length of the wire in the field (l) and the strength of the magnetic field (B). The magnitude of the force can therefore be calculated by the formula:

$$F = nBIl$$

F = Magnetic Force (**N**ewtons)
B = Magnetic field strength (**T**esla)
I = Current (**A**mperes)
l = length of wire in magnetic field (**m**eters)
n = Number of wires (**Just a number**)

The directions of the current, magnetic field and force can be obtained using the Right Hand Slap rule.

Note: To achieve the maximum force possible, the current and therefore the length of the wire should be perpendicular to the magnetic field. Else, the perpendicular component of the wire in respect to the direction of the magnetic field should be used in the equation. In this case, the magnitude of the force will be less that if the wire itself was directly perpendicular.

7. What are the main components of an electric motor? Draw a diagram and briefly explain each component.

There are three main components that comprise an electric D.C Motor.

- A permanent or electromagnet that creates a magnetic field (B)
- A loop of wire that pivots around a shaft capable of 360 degrees of ongoing rotation. The wire has a current passing through it. As the wire goes across a magnetic field created by the magnets or electromagnet, a force results; the direction of which can be determined using the Right-Hand Slap rule.
- A (Split Ring) Commutator. The commutator is responsible for reversing the flow of current through the wire loop resulting in a change in direction of the forces acting on loop causing it to rotate an additional 180 degrees. The commutator is a critical device within a motor as without it, the wire loop would not be able to complete a single rotation, thus rendering the motor useless. Wires from the battery rest against the commutator pieces and as the axle rotates (rotating the commutator with it), these pieces turn under the battery contacts called Brushes (small carbon blocks that allow current to flow).

  The Spilt Ring Commutator function is explained in more detail in Question #8 below.

Note: In a D.C Motor, the values of magnetic field strength (B), current (I) and the force (F) remain constant. What causes the rotation of the wire loop is the magnitude of the **torque** created about the shaft/axle or pivot point.

8. What is the function of a commutator in a D.C electric motor? Explain with a diagram.

The function of a commutator is the reverse the flow of current around the loop of wire every 180 degrees of rotation.

In a motor (as explained in Question #7), there are your 3 variables: Magnetic Field Strength (B), Current (I) and Force (F). The direction of the magnetic field remains constant, as does its size provided the magnitude of the current remains that same. We know by using the Right Hand Slap rule that having the magnetic field and current perpendicular to each other results in maximum force which in this case acts up on one side of the loop and down on the other (as current flows around from one side of the loop to the other). The forces on the loop create a turning effect called a **torque**, which rotates the loop. The direction and magnitude of the forces remain unchanging. As the loop rotates, the force has less and less turning effect until a point where the loop is perpendicular to the magnetic field, and the forces (which are still present and acting in the same direction as before) have no turning effect. Thus the rotation of the wire loop has stopped after only rotating 90 degrees or so. The motor is stuck. It will not move any further.

The split ring commutator reverses the flow of the current around the loop as it turns. So as the original forces reach the point where they have no more turning effect, the current is reversed. Using the Right Hand Slap rule to determine the direction, the forces acting on the loop are now in the opposite directions to what they were before – they have a new turning effect and therefore the loop can rotate another 180 degrees. After turning 180 degrees, the new forces once again have no more turning effect. Here, the commutator again reverses the current so the forces again switch to opposite directions, creating more torque to rotate the loop. The current must be reversed by the commutator twice every full rotation to ensure the motor keeps working.

The commutator is made up of two semicircular metallic conductors attached to the shaft or axle, each with a small insulating gap between. Each side of the loop is soldered to one side of the commutator halves. This ensures that as the ring rotates as the coil does. Wires from the battery or power supply rest against the metallic commutator pieces. As the shaft rotates, these pieces turn against the battery or power supply contacts called Brushes. This constant rotation allows the current to change direction every time the insulating gaps between the commutator pieces pass these brush contacts.

9. What is Magnetic Flux? Explain by use of formula and diagram. State units and make up your own worked example to illustrate this quantity.

Magnetic Flux (Φ) is defined as the amount of magnetic field passing though an area such as a coil, wire loop or solenoid. Magnetic flux is measured in the SI unit of **Webers** (**Wb**), where 1 Weber is the amount of magnetic flux from a magnetic field of strength 1 tesla that passes through and area of 1 meter squared.

Therefore, we can calculate magnetic flux by using the formula:

$$\Phi = B_{\perp} \times A$$

$$\text{Amount of magnetic flux } (\Phi) = \text{Strength of magnetic field, perpendicular to the area}(B) \times \text{the Area}(A)$$

Magnetic flux is a vector quantity; therefore it can have both positive and negative values indicating which side of the area it is coming from.

Note: It is very important that the magnetic field strength value (B) is taken at right angles to the area (A) when calculating magnetic flux. If the angle is less than 90 degrees, then the amount of magnetic flux passing through the area would be less. If the magnetic field is parallel to the area; that is, the angle is zero; then the amount of magnetic flux will be zero as none of the magnetic field will be able to pass through the area (In this case $\Phi = 0 \text{ Wb}$)

10. What is electromagnetic Induction and explain Faraday's Law. State this law and use 2 worked examples to illustrate its use.

Electromagnetic induction is the process of generating an Electromotive Force (emf), and as a result, a current because V = IR. This current can be generated in either one of two ways: In a coil as a result of a changing magnetic field (Example: Moving a magnetic through a ring or solenoid) or as a result of the movement of the coil or solenoid within a constant magnetic field. That is (in summary) either the wires move between stationary magnets or the magnets move and the wire remains stationary.

Faraday's Law states that: **The magnitude of the induced emf in a coil is directly proportional to the rate of change (derivative/gradient) of the magnetic flux passing through a coil.**

In other words, the emf that is induced via Electromagnetic induction in a coil is directly proportional to the rate that magnetic flux changes when passing through the coil (Magnetic flux being the amount of magnetic field that goes through a specific area – in this case the coil).

The size of the emf depends on how quickly the amount of magnetic flux changes.

Faraday's law can be represented in a formula by combining the concepts from Faraday's law iteself and Lenz's Law:

$$\varepsilon = \frac{-N\Delta\Phi}{\Delta \text{t}}$$

OR

$$\varepsilon = -N.\frac{d\Phi}{dt}$$

ε = Emf or Voltage (V)
N = Number of turns of loops in the wire (Just a number)
$\Delta\Phi$ = Change in magnetic flux (Wb)
Δt = Change in time (s)
n = Number of wires (**Just a number**)

The part that relates to Faraday's law is (Lenz's law just specifies direction):

$$\varepsilon = \frac{N\Delta\Phi}{\Delta \text{t}}$$

Using Faraday's law, we can calculate the amount of emf (and thus current) generated in via electromagnetic induction.

11. How do "dynamic microphones" work? Include in your answer a diagram and reference to induced EMF.

The function of a microphone is to convert sound vibrations into electrical signals for transmission or amplification. In a dynamic microphone, a soft diaphragm is connected to a tiny coil. When sound is received into the microphone, the diaphragm vibrates up and down on the coil (or spring). A permanent magnet is set inside the microphone within which rests the tiny coil. The diaphragm causes the coil to vibrate within the magnetic field when sound is received, producing a small induced EMF (and thus a small current), that's size varies according to the original sound.

(Diagram Source: Heineman Physics 12 – Units 3 & 4, p94)

12. What is Lenz's Law and illustrate how this is used to determine the direction of the induced current. Give several examples using diagrams.

Lenz's Law allows us to determine the direction that a current will flow in a circuit when an EMF is induced. It states:

"**That any induced current in a loop will be in the direction such that the [Magnetic] flux it creates will oppose the change in the [magnetic] flux which produced it**."

Thus in the formula combining Lenz's law with Faraday's, Lenz's Law gives it a negative sign to represent direction:

$$\varepsilon = \frac{-N\Delta\Phi}{\Delta \mathrm{t}}$$

Lenz's law is essentially another expression of the law of conservation of energy.
In summary:

- If the magnetic flux is INCREASING, the field created by the current will be in an opposite direction to the magnetic field. (That is, the direction of the induced magnetic field is REVERSED as is the direction of the induced current)

- If the magnetic flux is DECREASING, the field created by the current will be in the same direction as the magnetic field. (That is, the direction of the induced magnetic field remains THE SAME as does the direction of the induced current)

Lenz's law can be better understood by examining the diagrams below.

13. What is the formula for the EMF generated by coils rotating in a magnetic field at an angular speed? This is the formula for induced EMF in power generators. Give units and provide your own worked example.

Power generators use the concept of electromagnetic induction to transform mechanical or kinetic energy into electrical energy (The reverse of an electrical D.C. motor).

Recall that induced EMF is equal to the change in magnetic flux with respect to time. In other words the change in magnetic flux is the gradient function or derivative of a graph of EMF against time. This is because a graph of induced EMF is like a sine curve. As a loop in a generator rotates, the amount of magnetic flux passing through it is either constantly increasing or constantly decreasing. The result is that the EMF itself constantly increases and decreases. Therefore at the instant when the induced EMF is at maximum, there is zero magnetic flux passing though the loop. Similarly, when the magnetic flux passing through the loop is at maximum (loop is perpendicular to magnetic field) the EMF at that instant is zero. This can be represented by the combination of Faraday's and Lenz's laws:

$$\varepsilon = \frac{-N\Delta\Phi}{\Delta \mathrm{t}}$$

Or alternatively, we can use the formula:

$$\boldsymbol{\varepsilon_{max} = n \times B \times A \times 2\pi f}$$

ε = Emf or Voltage (V)
n = Number of turns in the loop (Just a number)
B = Magnetic field Strength (T)
A = Area of loop (m^2)
f = frequency of rotation (Hz)

14. Explain with a graph and your own worked example the meaning of peak, RMS, and peak-peak voltages and how these are related.

As stated in question #14, the output of an induced EMF from an AC Generator varies with time and produces a sinusoidal signal (often a sine curve when graphed).

The amplitude of a sine curve is the maximum variation from zero. In other words, it is the modulus of the maximum height or maximum value that a curve reaches (value taken from the Y-Axis), measured from zero. In electronics, we call the amplitude of an alternating (A.C.) voltage the **Peak Voltage** $(\boldsymbol{V_{peak}})$. Similarly, the amplitude of an alternating current is the **Peak Current** $(\boldsymbol{I_{peak}})$.

The **RMS** (Root Mean Square) **Voltage** is defined as the value or amount of DC Voltage you would require in order to produce the same amount of power as AC Voltage across the same resistance. In other words, if you were to replace an AC supply with a DC supply and wanted it to work just as well, you would need to ensure that the DC Supply matches the calculated RMS Voltage required. Example: 320 V (A.C) is equal to or is as effective as 240 V_{RMS} (D.C). We can determine the RMS value by relating it to the Peak Voltage of an AC Supply the equation:

$$V_{RMS} = \frac{V_{peak}}{\sqrt{2}}$$

Similarly the **RMS Current** (I_{RMS}) is the value of the amount of DC current you would need to match and generate the same power as an AC Current through the same resistance.

$$I_{RMS} = \frac{I_{peak}}{\sqrt{2}}$$

The definition of **Peak-Peak Voltage** (or **Peak-Peak Current**) is defined as the difference between the maximum and minimum voltages (or maximum and minimum currents) shown on a sinusoidal curve. In other words it is the difference between the positive (maximum) amplitude or Peak Voltage and the negative (minimum) amplitude. This can be simplified to 2 times the peak voltage or peak current.

$$V_{p-p} = 2 \times V_{peak}$$
$$I_{p-p} = 2 \times I_{peak}$$

15. What is three phase power? Explain with a diagram.

The power generated in power stations for transmission along lines is called **Three Phase Power**. It is a more efficient way of creating and distributing electrical power.

Inside a typical generator, there are 3 pairs of coils (instead of the usual one pair), each positioned at 120 degrees to each other that rotate around a central magnet. One end from each coil is connected to a single central point called the **neutral** or **neutral end**. The other ends of the coils are connected to one of three different outputs.

Three circuit conductors carry three alternating currents (of the same frequency, which are generated by the rotating coils around the magnet) which reach their peak values at different times. Using one conductor as a reference, the other two currents are delayed in time by one-third and two-thirds respectively of one cycle of the generated current. This delay between these "**phases**" has the effect of giving constant power transfer over each cycle of the current.

These conductors that carry the phases or alternating currents become a part of the high voltage power lines we see extending from power stations and across country sides. The neutral end discussed earlier is grounded into the earth at the power station. However, this neutral ground is seldom used because the three phases of alternating current always balance each other out as they are flowing in opposite directions. That is, across any time interval the average current is zero.

Three Phase power does not normally enter homes. It is split out into single phases, each which carries a load, at a Distribution Board.

16. Why do we transmit electricity at high voltages over long distances? Give a clear explanation and a worked example to show why it is necessary.

The current (or voltage) that is produced by a generator at power stations must travel extremely long distances until it reaches where it is needed. To achieve this, the electricity is transmitted to the consumer via long cables or Power Lines. However, as the electricity is flowing along such lengths of cable, some of its energy will be lost as heat. Transmitting electricity at higher voltages minimises this loss of energy and reduces its impact. Increasing the voltage decreases the amount of current flowing. It is important that the current (I value) is kept to a minimum during the transmission of electricity. The reason for this is that we define **Power** as the rate at which electrical energy is used or dissipated. Power is calculated by the formula:

$$P = I^2 R$$

P = Power (W), I = Current (A), R = Resistance (Ohms)

So the greater the size of the current flowing through the power lines, the more energy is lost. By "Stepping Up" the voltage as it leaves the power station (typically from 16kV to 220-500kV) and then by "Stepping Down" the voltage as it arrives at its destinations, the energy lost is kept at a minimum.

17. What are transformers and how do they work? Show a diagram and give a worked example. Do transformers work for Direct Current (D.C)? Why/Why not?

Transformers are devices used to scale the size of a voltage that is produced to a magnitude that is more appropriate for use. Often the voltage is either too large or too small. A transformer is useful as it rectifies this problem by changing the size of the voltage.

A transformer is made up of two coils of wire that are wound around an iron core, which increases the strength of the magnetic field induced on the coils. The first coil is called the **Primary Coil** and acts as the input for the A.C Voltage. The second coil is called the **Secondary Coil** and acts as the output for the A.C Voltage.

A transformer works on the principles of electromagnetic induction. That is, only when there is a change in magnetic flux in the coils and the connecting iron core does the transformer work.

When an A.C Voltage is applied to the Primary Coil, an alternating magnetic field is created within the iron core. This magnetic field gradually spreads to the Secondary Coil. At this point the alternating magnetic field induces and alternating voltage into the coil which is of identical frequency to the primary voltage.

In transformers, the power on either side is constant. In other words: The power input = the power output.

Transformers can only work with Alternating Current (A.C) and NOT Direct Current (D.C). This is due to the principles of electromagnetic induction. The transformer will only work when there is a change in magnetic flux. Unlike the concept of a power generator, because the iron core is not rotating, the only other way to vary to magnetic flux (i.e.: to get the magnetic flux to constantly change) is to vary the input EMF or voltage. Recall that when graphed, AC Voltage gives a sinusoidal curve. According to Faraday's Law, the EMF is equal to the derivative of the magnetic flux with respect to time. Graphing this derivative gives a cosine curve. When the EMF is at maximum, flux is zero. When flux is at maximum, the EMF is at zero. This variation in the AC Voltage causes the magnetic flux to constantly change: which the transformer needs to have happened in order to function!

If DC Current is used instead and is connected to the Primary Coil, then the Secondary Coil will only have an induced current when the switch to the battery is either opening or closing. The transformer cannot work like this.

In order to calculate the increase or decrease effects that a transformer has on a voltage and/or current, we can use the following relationships:

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

N_p = Number of turns in Primary Coil (Number)
N_s = number of turns in Secondary Coil (Number)
V_p = Voltage in Primary Coil (V)
V_s = Voltage in Secondary Coil (V)
I_s = Current in Secondary Coil (A)
I_p = Current in Primary Coil (A)

18. Discuss the difference between "Step Up" and "Step Down" transformers and give examples where each type is used.

Transformers are classified according to what they do to the voltage.

A **Step Up** transformer is one where the voltage in the secondary coil is larger than that in the primary. That is, the transformer has increased the size of the voltage. Example: When leaving a power station to travel along High Voltage Power Lines, the voltage needs to be increased so that minimal energy is lost during transmission (increasing the voltage decreases the current which in turn reduces the value for power (energy lost/used)). In this case, a Step Up transformer is used to increase the voltage.

A **Step Down** transformer is one where the voltage in the secondary coil is smaller than that in the primary. That is, the transformer has decreased or reduced the size of the voltage. Example: For use in many household appliances; 240 V_{RMS} is far too large to be used, else the appliances would explode or break down. 12 $V_{RMS}$is more appropriate. In this case, a Step Down transformer is used to decrease the voltage to a level appropriate and safe for use in appliances.

19. How is the electricity transmission system made efficient within practical/economic constraints? Explain and give your own worked example.

Due to the fact that electricity has to be transmitted over long distances through wires, the obvious inefficiency here is that energy is lost through heat while in transit due to the resistance in the wires. It is impractical to suggest that we lower the resistance of the wires by making them fatter or upgrading to a better conductor. For benefits of upgrading the wires to be seen, it would have to be done on a large scale. While this is possible, it would be too significantly costly and due to the sheer amount of power lines around Victoria, it would take far too long to replace all of them.

The amount of energy that is lost while in transmission through the power lines is defined by the power rating; which is given by the equation:

$$P = I^2 R$$

P = Power (W), I = Current (A), R = Resistance (Ohms)

As we have established that it is impractical to try and lower the value of the resistance to lower the subsequent Power value, the only other option is to lower the size of the current being transmitted through wires. As explained earlier, the reason why we use such high voltages when transmitting electricity is because the higher the size of the voltage, the lower the size of the current. As we can see from the equation, if R remains constant, the only way to have a low value for P is to have a low value for I. Therefore, the lower the size of the current, the less energy that is lost during transit.

Increasing the voltage and subsequently decreasing the current is well achievable within practical and economic constraints. Step Up and Step Down transformers can be used to, with about 100% efficiency, raise and lower the size of the voltages being transmitted at no significant cost (compared with if you were to replace all the power lines to decrease resistance).

20. How do we convert kWh to J (kilowatt hours to Joules)? Both units are a measure of electrical energy. Give an example.

1 Watt is defined as 1 Joule per second (1W = 1 J/s). So re-arranging this linearly:

1 Joule can be defined as 1 watt multiplied by 1 second, which is 1 Watt second (1J = 1W x 1s = 1Ws)

1 kilowatt (kW) = 1000 watts, also, 1 kilojoule (kJ) = 1000 Joules.

Therefore using our above definitions, 1 kilojoule = 1 kilowatt seconds (1kJ = 1 kWs). To return this to joules and watt seconds, simply multiply each side by 1000.

As there are 60 seconds in 1 minute and 60 minutes in one hour, one hour can be defined as 60 seconds x 60 minutes.

Therefore, 1 kilowatt hour (kWh) = (60 x 60) kilowatt seconds. = 3600 kilowatt seconds.

So knowing all this, we can now easily convert from kilowatt hours to joules:

1 kWh = 3600 kWs ← multiply by 1000 to obtain Watt Seconds
= 3,600,000 Ws ← Since 1 Joule (J) = 1 Watt Seconds (Ws)
= 3,600,000 J
=3.6 MJ (Megajoules)

So in general:
1 kWh = 3,600,000 J