Applied Physics 1

Power — Concept, Units, and Calculation

1. Power and Its Units

Power is defined as the rate at which work is done, or equivalently, the rate at which energy is transferred or transformed from one form to another. While work tells us how much energy has been transferred, power tells us how quickly that transfer takes place.

Mathematically, if an amount of work W is done in a time interval t, the average power P is given by:

- $P = W / t$

Power is a scalar quantity, since it is obtained by dividing one scalar quantity (work) by another scalar quantity (time).

The SI unit of power is the watt (W), named after the engineer James Watt. One watt is defined as the power of an agent that does one joule of work in one second:

- 1 watt (W) = 1 joule (J) / 1 second (s)

Some commonly used units of power, and their relation to the watt, are given below:

Unit	System	Relation to Watt
Watt (W)	SI	1 W = 1 J/s
Kilowatt (kW)	SI (multiple)	1 kW = 1000 W
Erg per second (erg/s)	CGS	1 W = 10^7 erg/s
Horsepower (HP)	British / Practical	1 HP = 746 W (approximately)

The horsepower is a practical unit still widely used to describe the power output of engines and motors, particularly in the automobile industry, even though the watt remains the standard SI unit used in scientific work.

2. Relationship Between Power and Work

Since power is defined as the rate of doing work, the relationship between power, work, and time can be summarised as:

- Work done, $W = P \times t$
- Power, $P = W / t$

- Time taken, $t = W / P$

This relationship shows that for a given amount of work, a more powerful machine takes less time to complete the work, while a less powerful machine takes a longer time to do the same amount of work. Similarly, for a given time interval, a more powerful machine can do a greater amount of work than a less powerful one.

Power can also be expressed in terms of the force applied and the velocity produced. If a constant force F acts on a body, causing it to move with a uniform velocity v in the direction of the force, then since work done $W = F \times s$ (where s is the displacement), power can be written as:

- $P = W / t = (F \times s) / t = F \times (s / t) = F \times v$

This gives the useful relation:

- $P = F \times v$

This form of the power relation is particularly useful in engineering applications, such as calculating the power developed by a vehicle's engine, a pump, or a crane, where the driving force and the resulting velocity are known or can be measured directly.

3. Calculation of Power — Numerical Problems

The following worked examples illustrate how the formulae $P = W/t$ and $P = F \times v$ are applied to calculate power in different practical situations.

Worked Example 1:
A machine does 500 J of work in 5 seconds. Calculate the power of the machine.

Solution: Using $P = W/t$, $P = 500 / 5 = 100$ W. The power of the machine is 100 watts.

Worked Example 2:
A pump lifts 200 kg of water through a height of 6 m in 10 seconds. Calculate the power of the pump. (Take $g = 10$ m/s^2)

Solution: Work done in lifting the water, $W = mgh = 200 \times 10 \times 6 = 12000$ J. Power, $P = W/t = 12000 / 10 = 1200$ W, or 1.2 kW.

Worked Example 3:
A car engine exerts a driving force of 2000 N while the car moves at a constant speed of 20 m/s. Calculate the power developed by the engine.

Solution: Using $P = F \times v$, $P = 2000 \times 20 = 40000$ W, or 40 kW.

Worked Example 4:

An electric motor of power 2 kW is used continuously for 3 hours. Calculate the total electrical energy consumed by the motor in kilowatt-hours and in joules.

Solution: Energy consumed, W = P × t = 2 kW × 3 h = 6 kWh. Converting to joules: 1 kWh = 3.6×10^6 J, so 6 kWh = $6 \times 3.6 \times 10^6 = 2.16 \times 10^7$ J.

These worked examples show that calculating power generally involves either dividing the total work (or energy) by the time taken, or multiplying the applied force by the resulting velocity, depending on the information available in a given problem.

4. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. Power is defined as the rate of doing:

A) Force
B) Work
C) Displacement
D) Momentum

2. The SI unit of power is:

A) Joule
B) Newton
C) Watt
D) Erg

3. One watt is defined as:

A) One joule of work done in one hour
B) One joule of work done in one second
C) One newton of force acting for one second
D) One joule of work done in one minute

4. The formula for average power is:

A) P = W × t
B) P = W / t
C) P = t / W
D) P = F / v

5. Power can also be expressed in terms of force and velocity as:

A) P = F + v
B) P = F / v
C) P = F × v
D) P = v / F

6. One horsepower is approximately equal to:

A) 74.6 W
B) 746 W
C) 7460 W
D) 7.46 W

7. Power is a:

A) Vector quantity
B) Scalar quantity
C) Dimensionless quantity
D) Constant for all machines

8. The dimensional formula of power is:

A) $[M^1L^2T^{-2}]$
B) $[M^1L^2T^{-3}]$
C) $[M^1L^1T^{-2}]$
D) $[M^1L^3T^{-2}]$

9. A machine that does more work in less time compared to another machine has:

A) Less power
B) Greater power
C) The same power
D) No power

10. 1 kilowatt is equal to:

A) 10 W
B) 100 W
C) 1000 W
D) 10000 W

11. The relation $P = F \times v$ is most useful for calculating the power of:

A) A stationary body
B) A vehicle or engine moving with velocity v under a driving force F
C) A body at rest under gravity
D) A body with zero force acting on it

12. Two motors A and B do the same amount of work, but motor A takes less time than motor B. Which motor has greater power?

A) Motor A
B) Motor B
C) Both have equal power
D) Cannot be determined

13. The commercial unit used for measuring electrical energy consumption is:

A) Watt

B) Joule
C) Kilowatt-hour (kWh)
D) Horsepower

14. If a machine does 500 J of work in 5 seconds, its power is:
A) 50 W
B) 100 W
C) 500 W
D) 2500 W

15. Power measures how quickly:
A) A force acts on a body
B) Work is done or energy is transferred
C) A body changes its mass
D) A body changes its shape

Answer Key

1. B) Work | 2. C) Watt | 3. B) One joule of work done in one second | 4. B) P = W / t | 5. C) P = F × v | 6. B) 746 W | 7. B) Scalar quantity | 8. B) $[M^1L^2T^{-3}]$ | 9. B) Greater power | 10. C) 1000 W | 11. B) A vehicle or engine moving with velocity v under a driving force F | 12. A) Motor A | 13. C) Kilowatt-hour (kWh) | 14. B) 100 W | 15. B) Work is done or energy is transferred

5. Broad / Long Answer and Numerical Questions

1. Define power. Explain why power is regarded as a measure of the rate of doing work, using a suitable example to distinguish it from work itself.

2. State the SI unit of power and define it. Explain the relationship between the SI unit of power and the SI units of work and time.

3. Derive the relation P = F × v for the power delivered by a constant force acting on a body moving with velocity v.

4. Define horsepower. State its relation to the watt, and explain where this unit is commonly used in practice.

5. Explain, with an example, why two machines doing the same amount of work can have different power ratings.

6. Explain the difference between work, energy, and power, bringing out clearly how the three quantities are related to one another.

7. A pump lifts 200 kg of water through a height of 6 m in 10 seconds. Calculate the power of the pump. (Take $g = 10\ m/s^2$)

8. A machine does 3000 J of work in 15 seconds. Calculate its power in watts, and also express this power in horsepower.

9. A car engine exerts a driving force of 2000 N while the car moves at a constant speed of 20 m/s. Calculate the power developed by the engine.

10. An electric motor of power 2 kW is used continuously for 3 hours. Calculate the total electrical energy consumed by the motor in kilowatt-hours, and also express this energy in joules.