31

Water Wheels

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31·1 Introduction

The idea of using water, as a source of mechanical energy, existed since the dim ages of pre-historic times. The hydraulic energy was first converted into mechanical energy in India about 2200 years back, by passing the water through water wheels. These water wheels were originally made of wood, and are seen in technical museums even now. Such type of water wheels were taken from India to Egypt and then to European countries, and finally to America. It is believed that the water wheel was used in Europe about 500 years after its origin in India.

The systematic design of water turbines, from the water wheels, started, in 18th century. These days, lot of research is being conducted all over the world to improve upon the various existing turbines.

31·2 Types of Water Wheels

The water wheels may be broadly classified into the following three groups, depending upon the driving action of the water:

1. Wheels driven by weight of water.
2. Wheels driven partly by weight and partly by impulse of water.
3. Wheels driven entirely by impulse of water.

In general practice, a water wheel consists of a central hub and a circular wheel having a number of buckets or vanes mounted on its periphery. The water is delivered to the wheel at some convenient point on its circumference, which fills into the buckets or strikes the vanes. The following types of water wheels have been used in the olden days:

(*a*) Overshot wheel and breast wheel, and

(*b*) Undershot wheel.

31·3 Overshot Water Wheel

An overshot wheel, as the name indicates, is a water wheel in which the water enters the buckets at the top of its periphery as shown in Fig. 31·1. This wheel runs entirely by the weight of water (sometimes partly by the impulse of water).

The water, from the head race, is allowed to enter the buckets through an adjustable sluice gate. The weight of water forces the buckets downwards, and thus makes the wheel to rotate. The buckets get emptied into the tail race, as they approach the lower position. The buckets are so arranged, that the maximum water energy is utilized. Sometimes, the crown of the wheel is made slightly below the head race, as a result of which the water strikes the buckets with some initial velocity. In such case, the wheel is driven partly by weight and partly by impulse of water. The overshot wheels have the following constructional details:

Head of water, H = 10 to 25 m
Dia. of wheel, D = 3 to 20 m
No. of buckets, = 8 to 10 D
Speed of wheel, N = 4 to 8 r.p.m.
Depth of shroud = 0·5 to 1·0 m
Efficiency, η = 60 to 80%

The power available from an overshot water wheel is given by the relation,

$$P = wQH \text{ kW}$$

If η is the efficiency of the wheel, then actual power available,

$$P = \eta \times wQH \text{ kW}$$

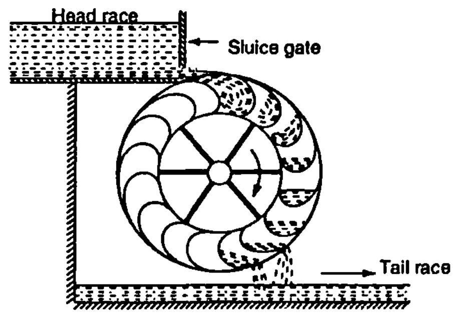

Fig. 31·1. Overshot water wheel.

and discharge of the wheel is given by the relation,

$$Q = k.b.d.v = k.b.d \times \frac{\omega D}{2}$$

where k = Fraction of the buckets filled with water,
b = Width of the buckets,
d = Depth of shrouds,
v = Velocity of the buckets,
ω = Angular velocity of the wheel, and
D = Diameter of the wheels.

Example 31·1. *An overshot water wheel has approaching canal 1·5 m wide. The water flows in the canal with a velocity of 1·5 m/s and 200 mm deep. Determine the power available from the water wheel, if the waterfall is 20 m and the efficiency of wheel is 75%.*

Solution. Given : Canal width (b) = 1·5 m; v = 1·5 m/s; d = 200 mm = 0·2 m; H = 20 m and η = 75% = 0·75.

We know that discharge,

$$Q = a.v = (b.d)v = 1·5 \times 0·2 \times 1·5 = 0·45 \text{ m}^2$$

and power available from the water wheel,

$$P = \eta \times wQH = 0·75 \times 9·81 \times 0·45 \times 20 = 66·2 \text{ kW} \textbf{ Ans.}$$

Example 31·2. *An overshot water wheel 5 m diameter has 500 mm deep shrouds. It is required to produce 12 kW at 5 r.p.m. Assuming the buckets to be 1/3 filled with water, find the width of the wheel when the total fall is 6 m. Take efficiency of the wheel is 70%.*

Solution. Given : D = 5 m; d = 500 mm = 0·5 m; P = 12 kW; N = 5 r.p.m.; k = 1/3; H = 6 m and η = 70% = 0·7.

Let b = Width of the wheel.

We know that angular velocity of the wheel,

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 5}{60} = 0·524 \text{ rad/s}$$

and discharge of the wheel,

$$Q = k.b.d \times \frac{\omega D}{2} = \frac{1}{3} \times b \times 0·5 \times \frac{0·524 \times 5}{2} \text{ m}^3\text{/s}$$

We also know that power of the wheel (P),

$$12 = \eta \times wQH = 0{\cdot}7 \times 9{\cdot}81 \times (0{\cdot}218\, b) \times 6 = 8{\cdot}98\, b$$

$$\therefore \qquad b = 12/8{\cdot}98 = 1{\cdot}34 \text{ m} \quad \textbf{Ans.}$$

31·4 Breast Water Wheel

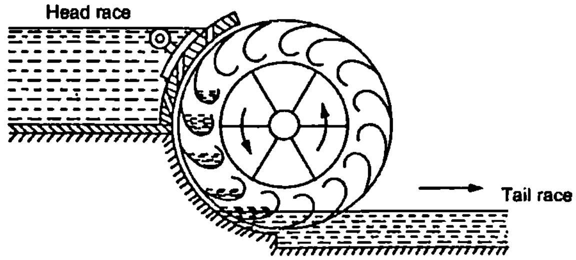

Fig. 31·2. Breast water wheel

A breast wheel, as the name indicates, is a water wheel in which the water enters the buckets at the breast height of the wheel as shown in Fig. 31·2. This wheel runs partly by weight and partly by the impulse of water.

The water, from the head race, is allowed to enter the buckets without shock through a number of passages which may be opened or closed by rock and pinion arrangement as shown in Fig. 31·2. The buckets move downwards due to weight of water, and thus make the wheel to rotate. The special feature of the wheel is that its bottom is immersed in the tail race water. As the direction of the motion of the wheel and the flow of the tail race water is the same, therefore the water while flowing further rotates the wheel. That is why, the wheel is the said to run partly by weight and partly by the impulse of water. Another special feature of this wheel is that the diameter of the wheel is more than the head of water available. A breast wheel has the following constructional details:

Head of water,	H =	1 to 5 m
Dia. of wheel,	D =	4 to 8 m
Speed of wheel,	N =	3 to 7 r.p.m.
Depth of shroud	=	300 to 600 mm
Efficiency,	η =	50 to 65%

The power available from a breast water wheel is also given by the relation,

$$P = \eta \times wQH \text{ kW}$$

Example 31·3. *A breast wheel of 8 m diameter and 2 m width is working under a head of 5 m. The depth of shroud is 400 mm and the buckets move with a velocity of 1.5 m/s with 5/8 full. Calculate the power of the wheel, if its efficiency is 60%.*

Solution. Given : $D = 8$ m = $b = 2$ m; $H = 5$ m; $d = 400$ mm = 0·4 m; $v = 1{\cdot}5$ m/s; $k = 5/8$ and $\eta = 60\% = 0{\cdot}6$.

We know that discharge of the wheel,

$$Q = k\,.\,b\,.\,d\,.\,v = \frac{5}{8} \times 2 \times 0{\cdot}4 \times 1{\cdot}5 = 0{\cdot}75 \text{ m}^3/\text{s}$$

and power of the wheel,

$$P = \eta \times wQH = 0{\cdot}6 \times 9{\cdot}81 \times 0{\cdot}75 \times 5 = 22{\cdot}1 \text{ kW} \quad \textbf{Ans.}$$

31·5 Undershot Water Wheel

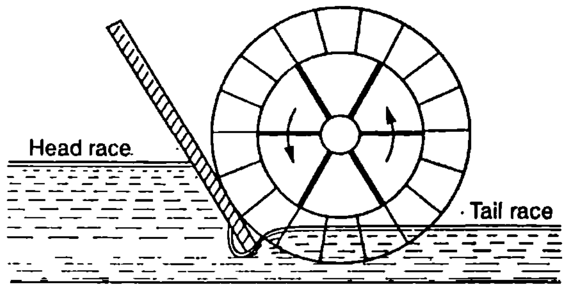

Fig. 31·3. Undershot water wheel.

An undershot wheel, as the name indicates, is a water wheel in which the water in the form of jet impinges on the straight blades (vanes) fitted at the bottom of its periphery as shown in Fig. 31·3. This wheel runs entirely by the impulse of water as the jet of water strikes on the vanes, and thus makes the wheel to rotate. The available head of water is first converted into velocity head, before the water strikes the buckets of the wheel. The undershot wheels have the following constructional details:

Head of water,	$H < 2$ m
Dia. of wheel,	$D = 2$ to $4\ H$
Speed of wheel,	$N = 2$ to 4 r.p.m.
Efficiency,	$\eta = 35$ to 45%

The power available from an undershot water wheel is also given by the relation,

$$P = \eta \times wQH \quad \text{kW}$$

Note : The theory of an undershot water wheel is the same as that of series of moving vanes (Art. 29·6).

Example 31·4. *An undershot wheel is working under a head of 2·5 m with a speed of 5 r.p.m. Find the diameter of the wheel, if its efficiency is 40%. Take coefficient of velocity as 0·98 and ratio of peripheral velocity of the wheel to the velocity of the jet as 0·46.*

Solution. Given : $H = 2.5$ m; $N = 5$ r.p.m ; $\eta = 40\% = 0.4$; $C_v = 0.98$ and $v = 0.6\ V$ (where V is the velocity of jet).

Let $\quad D =$ Diameter of the wheel.

We know that the velocity of jet,

$$V = C_v \sqrt{2gH} = 0.98 \times \sqrt{2 \times 9.81 \times 2.5} = 6.86 \text{ m/s}$$

and peripheral velocity of wheel,

$$v = 0.46\ V = 0.46 \times 6.86 = 3.16 \text{ m/s}$$

We also know that the peripheral velocity of the wheel (v),

$$3.16 = \frac{\pi DN}{60} = \frac{\pi \times D \times 5}{60} = 0.262\ D$$

$$\therefore \quad D = 3.16/2.62 = 1.21 \text{ m} \quad \textbf{Ans.}$$

31·6 Poncelet Water Wheel

It is an improvement over the straight blade type undershot water wheel. The straight blades of the undershot wheel are replaced by curved vanes as shown in Fig. 31·4. This wheel runs entirely by

The vanes are curved at such an angle, that the jet of water enters the vanes tangentially (*i.e.*, without shock). The blades are made sufficiently long, so that the water does not spill over at the outlet; but actually flows down to the tail race as shown in Fig. 31·4.

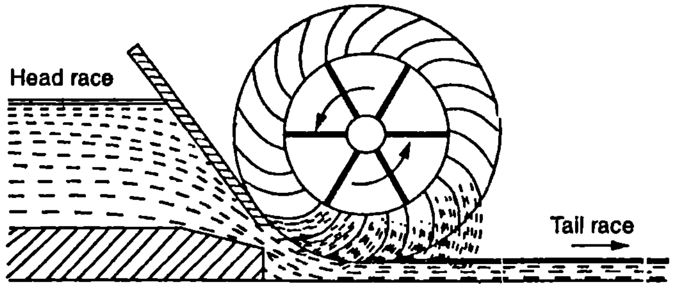

Fig. 31·4. Poncelet water wheel.

As a result of this, the efficiency of the wheel is doubled. The Poncelet wheel has the following constructional details:

Head of water,	H	= 2 to 3 m
Dia. of wheel,	D	= 2 to 4 H
Speed of wheel,	N	= 2 to 5 r.p.m.
Efficiency,	η	= 55 to 65%
Inlet angle	α	= 15°

The power available from a Poncelet water wheel is also given by the relation,

$$P = \eta \times wQH \text{ kW}$$

Note : The theory of a Poncelet water wheel is the same as that of moving curved vane (Art 29·8).

Example 31·5. *In a Poncelet wheel, the jet enters the curved vanes with a velocity of 7 m/s at an angle of 20° with the direction of motion of tip of the vanes. If the edge of the wheel moves with a velocity of 5·5 m/s, find the angle which the vanes make with the tangent.*

Solution. Given : $V = 7$ m/s; $\alpha = 20°$ and $v = 5{\cdot}5$ m/s.

Let θ = Angle which the vanes make with the tangent.

From the inlet triangle of velocities, we find that

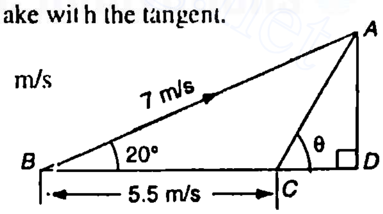

Fig. 31·5.

$$BD = V \cos 20° = 7 \times 0{\cdot}9397 \text{ m/s}$$
$$= 6{\cdot}58 \text{ m/s}$$

and

$$AD = V \sin 20°$$
$$= 7 \times 0{\cdot}342 \text{ m/s}$$
$$= 2{\cdot}4 \text{ m/s}$$

We know that

$$CD = BD - BC = 6{\cdot}58 - 5{\cdot}5 \text{ m}$$
$$= 1{\cdot}08 \text{ m}$$

and

$$\tan\theta = \frac{AD}{CD} = \frac{2{\cdot}4}{1{\cdot}08} = 2{\cdot}222 \quad \text{or} \quad \theta = 65{\cdot}8° \quad \textbf{Ans.}$$

Example 31·6. *In a Poncelet water wheel, the direction of the jet is at an angle of 15° with the tangent and the tip of the vane makes an angle of 30° with the tangent. If velocity of the jet is 10 m/s, find (i) velocity of the edge of the wheel, and (ii) velocity and direction of water leaving the float.*

Solution. Given : $\alpha = 15°$; $\theta = 30°$ and $V = 10$ m/s.

Velocity of the edge of the wheel

and $AD = V \sin 15° = 10 \times 0{\cdot}2588$ m/s

$= 2{\cdot}588$ m/s

or $CD = \dfrac{AD}{\tan 30°} = \dfrac{2{\cdot}588}{0{\cdot}5774} = 4{\cdot}482$

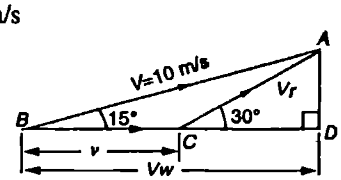

Fig. 31·6.

∴ Velocity of the edge of the wheel,

$v = BC = BD - CD$

$= 9{\cdot}659 - 4{\cdot}482 = 5{\cdot}177$ m/s **Ans.**

Velocity of water leaving the float

Let V_1 = Velocity of water leaving the float.

From the inlet triangle of velocities we find that it is an isosceles triangle, as $\angle ACD$ is twice the angle $\angle ABC$. Therefore relative velocity,

$V_r = CA = BC = 5{\cdot}177$ m/s

Now from the outlet triangle of velocities, we find that the relative velocity,

$V_{r1} = V_r = LM = 5{\cdot}177$ m/s

and velocity of edge of the wheel,

$v_1 = v = MN = 5{\cdot}177$ m/s

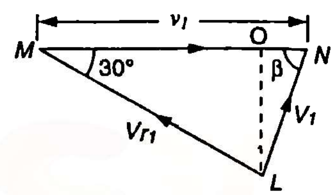

Fig. 31·7.

∴ $MO = V_{r1} \cos 30° = 5{\cdot}177 \times 0{\cdot}866 = 4{\cdot}483$ m/s

and $LO = V_{r1} \sin 30° = 5{\cdot}177 \times 0{\cdot}5 = 2{\cdot}589$ m/s

Since MN (equal to 5·177) is more than MO (equal to 4·483), therefore shape of the outlet triangle will be as shown in Fig. 31·7.

Now $ON = MN - MO = 5{\cdot}177 - 4{\cdot}483 = 0{\cdot}694$ m/s

∴ Velocity of water leaving the float,

$V_1 = LN = \sqrt{(2{\cdot}589)^2 + (0{\cdot}694)^2} = 2{\cdot}68$ m/s **Ans.**

Direction of water leaving the float

Let β = Angle at which the water leaves the float.

From the geometry of the outlet triangle of velocities, we find that

$$\tan \beta = \frac{LO}{ON} = \frac{2{\cdot}589}{0{\cdot}694} = 3{\cdot}73 = 75° \quad \textbf{Ans.}$$

31·7 Advantages and Disadvantages of Water Wheels

The water wheels have the following advantages and disadvantages :

Advantages

1. They are simple and strong in construction.
2. They are suitable even for low water heads.
3. They are cheaper.
4. They give constant efficiency, even if the discharge is not constant.

Disadvantages

1. They have slow speeds.
2. They are heavier and bigger, if compared with their capacity to produce power.

... suitable for high water heads.

31·8 Development of Water Turbines

In the previous article, we have discussed the disadvantages of water wheels. Moreover, the hydro power was available mostly in rural and mountainous regions. As a result of this, the mills directly run by water wheels, had to be installed near the power stations. The prime movers had to run round the clock, even if some of the machines in the mills may remain idle. It was also observed that the slow moving water wheels were not suitable for all types of purposes. Lot of research was conducted by numerous scientists and engineers all over the world, to improve the working of water wheels in the 18th and 19th centuries. As a result of this research, water turbines were designed, which can operate under high head (highest head 1765 metres in Austria) and can run at higher speeds.

After the first world war, there came the evolution in the use of electric power. The use of electricity, for driving machines in industry, being very convenient to handle became very common. Side by side, with the mammoth research in electric power, high speed machines were designed. Due to rapid increase in the use of electric power, the transmission of electricity, from remote hydro power stations to the far off places, was considered necessary. Due to the above mentioned reasons, the water turbines occupied an important position among prime movers. Today, the water turbines are taken to be the back bone of electricity, which is considered to be one of the important factors for the prosperity of a nation.

31·9 Advantages of Water Turbines

The water turbines have the following advantages over water wheels or any other type of prime movers:

1. They have long life.
2. They are efficient and can be easily controlled.
3. They have outstanding ability to act as standby unit.
4. They can be made automatic controlled.
5. They can work under any head.

31·10 Classification of Water Turbines

The water turbines may be broadly classified into the following two groups:

1. Impulse or velocity turbines, and
2. Pressure or reaction turbines.

The various water turbines, belonging to both the above groups will be discussed at the appropriate place of this book.

31.11 Recent Trends in Water Power Engineering

The crying need of more and more electric energy has drawn the attention of scientists and engineers, working in the research and development programmes, to generate electricity. They have focussed their attention on:

1. Hydroelectric power,
2. Thermal power, and
3. Atomic power.

In this book, we shall discuss the hydroelectric power only, as the others are beyond the scope of this book.

31·12 Hydroelectric Power Plant

It consists of the following main components :

1. Storage reservoir,
2. Dam and its parts,
3. Water ways,
4. Water turbines and electric generators

1. *Storage reservoir*

The water available from the catchment area is stored in the reservoir. The capacity of reservoir should be such that the water should be available for running the turbines, for producing the desired quantity of electric power, throughout the year. A reservoir may be natural or artificial.

2. *Dams and its parts*

A dam is constructed across a river in order to check the flow of water and impound it in the reservoir formed on the upstream side. The size and type of dam depends upon the character of river, head of water, amount of discharge etc. Its shape and other components are decided by tests on model in the laboratory.

The dams are provided with gates for regulating the flow of water. There is also an arrangement for automatic overflow of excess water. Some means are also provided for removing silt from the reservoir just closer to the dam. It is still a problem, which the engineers working on the maintenance of dams, have not been able to solve it successfully.

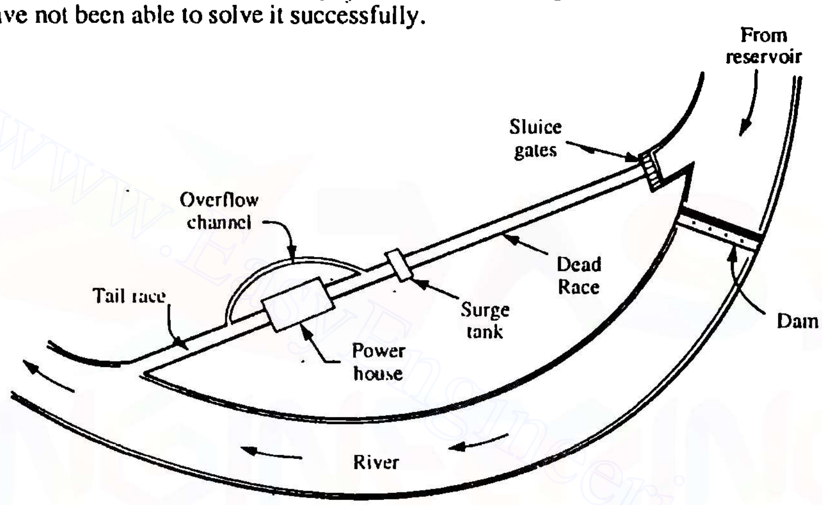

Fig. 31·8. Hydroelectric power plant.

3. *Water ways*

A waterway is a passage through which the water is carried from the dam to the power house and then to the river. The upstream portion is known as head race and the downstream as tail race. It may consist of tunnels, canals, flumes, pipes or any other suitable arrangement. A surge tank is also provided just on the upstream of the power house to control the pressure variation and eliminate the effects of water hammer.

4. *Water turbines and electric generators*

A place, where water turbines and electric generators are installed, is called power house. Its design is very complicated and requires lot of skill. In this book, we shall discuss the design of water turbines only, as the design of electric generator is beyond the scope of this book.

The position of a power house is decided by considering factors such as space available, transport facilities etc. The size of a power house is decided by considering the factors such as supply height, number and size of units, type of units electrical arrangements etc. The electrical generators are directly coupled with the turbines for better efficiency.

The turbines may be designed and laid either with their shafts horizontal or vertical. In a horizontal shaft lay out, the whole installation lies on the same floor. Thus it is very easy to carry out inspection, service or any other modification in the plant. In a vertical shaft lay out, it is convenient to connect incoming pipe and outgoing draft tube. Moreover, the generators are spaced well above the water surface, which makes their inspection, service and maintenance easier.

The general layout of a hydroelectric power project is shown in Fig. 31·8.

Note : There is a definite relation between the speed of the turbine rotor and the frequency of A.C. alternator, which is given by:

$$\frac{120f}{p} = n$$

where f = Frequency in cycles/s,

p = No. of poles in alternators (which must be an even integral number, because they exist in pairs, and

n = Synchronous speed of the turbine rotor in r.p.m.

If the number of poles works out to be in decimal or odd number, then the next even number is selected.

EXERCISE 31·1

1. An overshot wheel is working under a head of 4 m. If 0·5 m^2 of water flows over the wheel in one second, find the power developed by wheel. Take efficiency of the wheel as 45%. **(Ans. 8·83 kW)**
2. An overshot wheel is working under a head of 6 m. The diameter of the wheel is 6·5 m, width 250 mm has 300 mm deep shrouds. Assuming the buckets to be 1/3 filled with water, find the power available from the wheel. Take efficiency of the wheel as 50%. **(Ans. 7·9 kW)**
3. A breast wheel of 5 m diameter 1 m wide is working under a head of 4·5 m. The depth of the shrouds is 400 mm and buckets move with a velocity of 1·2 m/s with half full. Determine the efficiency of the wheel, if it produces 5·5 kW power. **(Ans. 50·9%)**
4. In a Poncelet water wheel, the direction of jet is at angle of 30° with the tangent to the circumference. If the velocity of the jet is 4·5 m/s and that of the edge of the wheel is 2·25 m/s, determine the angle which the vane makes with the tangent. **(Ans. 53·8°)**

QUESTIONS

1. What is a 'water wheel'? Explain the various forms of water wheels.
2. Distinguish clearly between:
   (*a*) Overshot water and undershot water wheel.
   (*b*) Undershot water wheel and Poncelet water wheel.
3. Give the advantages and disadvantages of water wheels.
4. Give the advantages of water turbines.
5. What is a hydroelectric power project? Write a short note on its various parts.

OBJECTIVE TYPE QUESTIONS

1. The water wheels run by
   (*a*) weight of water (*b*) impulse of water (*c*) neither '*a*' nor '*b*' (*d*) both '*a*' and '*b*'
2. Water wheels are suitable for
   (*a*) low water heads (*b*) high water heads (*c*) very high water heads (*d*) all of these
3. The water wheels
   (*a*) are simple in construction (*b*) are cheaper in cost
   (*c*) have constant efficiency (*d*) all of these
4. The power developed by a water wheel is equal to
   (*a*) $\frac{wQH}{2}$ (*b*) wQH (*c*) $2wQH$ (*d*) $\frac{wQH^2}{2}$

Answers

1. (*d*) 2. (*a*) 3. (*d*) 4. (*b*)