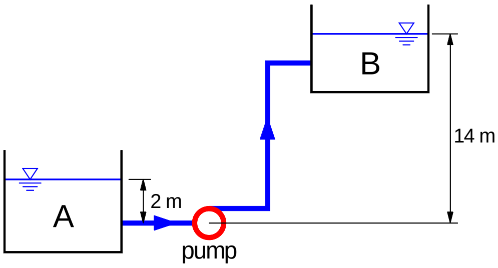
Q1.
Water is pumped from tank A to tank B (see figure). The relative heights of free surfaces and the pump are as shown, whilst pump characteristics at the operational speed are given below.

Discharge (L s^{-1}):	0	3	6	9	12	15	18
Head (m)	30	29.5	27.6	24.4	19.7	13.5	5.9
Efficiency (%)	–	29	54	73	80	70	38

The pipework has overall length 40 m and diameter 0.06 m. The friction factor is 0.02 and minor losses may be neglected.



(a) Derive the system characteristic (i.e. head as a function of discharge, stating carefully the units for head and discharge).

(b) Find the discharge and power consumption at the duty point.

(c) In a bid to increase the total discharge a second pump of similar type is added. Assuming that the pumps are run at the same operational speed and that the system characteristic is unchanged, find the total discharge and power consumption if the pumps are connected: (i) in parallel; (ii) in series.

Q2. (Exam 2019)
A variable-speed pump draws water from a reservoir to an elevated tank. The difference in water levels between the reservoir and the tank is 22 m. The pipe between them has length $L = 400$ m, diameter $D = 180$ mm and friction factor $\lambda = 0.05$. Minor losses can be neglected. The characteristics of the pump at the nominal speed of 2400 rpm are given in the table below.

Pump characteristics at 2400 rpm

Discharge (L s^{-1})	15	23	31	39	47
Head (m)	35.1	33.3	29.1	22.1	13.1
Efficiency (%)	47.1	64.2	71.3	61.8	39.3

(a) Find the system characteristic (head as a function of discharge), giving numerical values of the function coefficients and stating the units used for head and discharge.

(b) Find the flow rate and the power consumption at the duty point.

(c) After a rearrangement of the facilities, a valve is installed at the end of the pipe. The pump speed is increased to 2800 rpm and the valve is partially closed so that the pump operates at its maximum efficiency. Determine:
(i) the duty point (discharge and head) and power consumption of the pump;
(ii) the head loss at the valve.

Q3. (Exam 2018)

A variable-speed pump draws water from a reservoir to an elevated tank. The difference in water levels between the reservoir and the tank is 10 m. The pipe between them has length $L = 250$ m, diameter $D = 150$ mm and friction factor $\lambda = 0.025$, which can be assumed to be constant. Minor losses can be neglected. The characteristics of the pump at the operational speed are given in the table below.

Pump characteristics at 2400 rpm

Discharge (L s^{-1})	14	22	30	38	46
Head (m)	37.5	35.5	30.9	23.2	13.3
Efficiency (%)	57.1	73.1	78.2	67.8	43.0

(a) Find the system characteristic (head as a function of discharge), giving numerical values of the function coefficients and stating the units used for head and discharge.

(b) Find the flow rate and the power consumption at the duty point.

(c) To increase the flow rate, a second identical pump is installed and operated in parallel with the existing pump. In the new configuration, both pumps work at the reduced rotational speed of 2200 rpm. Determine the flow rate and the power consumption at the new duty point.

Q4. (Exam 2021)

Water is pumped from a storm-water retention tank to a water-treatment works (WTW) by a pump adjacent to the retention tank. A single main pipe, which has length 3 km, diameter 300 mm and friction factor 0.02 leads from the pump to the WTW, which is 10 m above the water level in the tank. The characteristics of the pump are given in the table below.

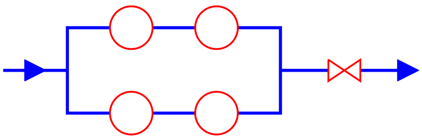
Pump characteristics

Discharge, Q (L s^{-1})	10	20	30	40	50	60
Head, H (m)	24.5	22.7	19.3	14.5	8	0
Efficiency, η (%)	30	55	72	73	52	0

(a) Neglecting losses other than the frictional losses in the main delivery pipe, find the system characteristic (head as a function of discharge), giving numerical values and stating the units used for head and discharge.

(b) Find the discharge to the WTW and the total power consumption.

Four identical pumps with the characteristics given in the table are now installed as illustrated in the figure. A valve is installed on the delivery pipe to control the discharge.



(c) If the valve is completely open and minor losses are negligible, find the new discharge and power consumption.

(d) If the valve-regulated discharge is 70 L s^{-1}, determine the head loss at the valve.

Q5.
A centrifugal pump is used to pump water out of a flooded basement. The water must be raised a vertical height of 6 m through a pipe of length 50 m, diameter 70 mm and friction factor 0.04. Pump characteristics at 1500 rpm are given below.

Discharge, Q (L s^{-1})	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
Head, H (m)	8.92	8.00	7.02	5.99	4.91	3.76	2.56	1.31
Efficiency, η (%)	-	30.6	52.5	65.6	70.0	65.6	52.5	30.6

(a) Determine the system characteristic (head loss H as a function of discharge Q), giving numerical values and stating the units of H and Q.

(b) Determine the time taken to pump one cubic metre of water and the total energy used by the pump in this time. (Assume negligible change in water levels).

(c) If the pump speed is increased to 2250 rpm calculate the time taken to pump one cubic metre of water.

Q6. (Exam 2017)
A variable-speed pump draws water from a reservoir to an elevated tank. The difference in water levels between the reservoir and the tank is 12 m. The pipe between them has length $L = 400$ m, diameter $D = 150$ mm and friction factor $\lambda = 0.03$. Minor losses can be neglected. The characteristics of the pump at the operational speed are given in the table below.

Pump characteristics at 2400 rpm

Discharge (L s^{-1})	14	22	30	38	46
Head (m)	34.1	32.3	28.1	21.1	12.1
Efficiency (%)	51.9	67.0	71.1	61.6	39.1

(a) Find the system characteristic (head as a function of discharge), giving numerical values of the function coefficients and stating the units used for head and discharge.

(b) Find the flow rate and the power consumption at the duty point.

(c) After several years of use, deterioration of the pipe has caused the friction factor to increase. To maintain the same flow rate, the rotational speed of the pump has been increased to 2600 rpm. Determine:
  (i) the head developed by the pump and the power consumption at the new duty point;
  (ii) the friction factor of the deteriorated pipe.

Q7.

A pump is required to lift water from a sump to an upper-level tank, the difference in water levels being 12 m. The pump intake is 2 m below the water level in the sump. A pipe of diameter 150 mm runs 10 m from sump to pump intake and a pipe of the same diameter runs 25 m from pump outlet to the upper tank. The friction factor in both pipes is $\lambda = 0.025$; minor losses may be neglected.

The pump characteristics at its operational speed are as follows. (Q is discharge; H is head across the pump; η is efficiency).

Q (m^3 s^{-1})	0.00	0.03	0.06	0.09	0.12	0.15	0.18
H (m)	30.0	29.8	28.1	25.0	20.4	14.1	6.2
η (%)	–	29	54	73	80	70	38

(a) Find the system characteristic (i.e. head as a function of discharge), including all numerical values.

(b) At the duty point find:
  (i) the discharge;
  (ii) the power consumption of the pump;
  (iii) the gauge pressure at pump inlet.

(c) Following an upgrade a geometrically-similar pump is installed which runs at the same rotational speed but has an impeller 1.2 times the size. Assuming hydraulic similarity, plot the new pump characteristics (H vs Q and η vs Q) and find the discharge and power consumption at the new duty point.

Q8.
The characteristics of two constant-speed rotodynamic pumps are as follows.

Pump A

Discharge (L s^{-1})	0	6	12	18	24	30	36
Head (m)	22.6	21.9	20.3	17.7	14.2	9.7	3.9
Efficiency (%)	–	32	74	86	85	66	28

Pump B

Discharge (L s^{-1})	0	6	12	18	24	30	36
Head (m)	16.2	13.6	11.9	11.6	10.7	9.0	6.4
Efficiency (%)	–	14	34	60	80	80	60

It is required to select one of these pumps to lift water continuously through 3.2 m via pipework of total length 21 m, diameter 100 mm and friction factor $\lambda = 0.02$.

(a) Find the system characteristic (head as a function of discharge), giving numerical values and the units that you have chosen to use for head and discharge.

(b) Assuming that both A and B can both pump water at an adequate rate, select the more suitable pump for this duty, justifying your selection.

(c) What power input will be required by the selected pump?

(d) Because of siting constraints the pump has to be located half way along the pipe at the same elevation as the final delivery point. Determine whether cavitation is likely to be a problem for your selected pump. (Assume that the vapour pressure of water at this temperature is 95 kPa below atmospheric pressure.)

Q9.
A variable-speed pump is used to pump water from a storm-water collection tank to a water-treatment works. The water level in the storm-water collection tank is below ground level at -3 m AOD, whilst the still-water level in the treatment works is 12 m AOD. The pipeline connecting the two is of length 800 m, diameter 0.4 m and has a friction factor $\lambda = 0.02$. Pump characteristics (head H and efficiency η as functions of discharge Q) are given in the following table when the pump is running at 1400 rpm.

Pump characteristics at 1400 rpm

Q (m^3 s^{-1})	0.0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45
H (m)	29.6	30.0	29.6	28.4	26.5	23.9	20.5	16.6	12.1	7.2
η (%)	0	49	70	79	77	69	55	38	21	5

(a) Find the system characteristics (head as a function of discharge), giving numerical values and stating the units used for head and discharge.

(b) Find the discharge when the pump is operating at 1400 rpm and the energy consumed by the pump in delivering 100 m^3 of water.

(c) Find the most efficient discharge and pumping head when the pump is operating at 1400 rpm and give a mathematical expression (with numerical values and units) for the relationship between the head and discharge at the maximum-efficiency point as the pump rotation rate changes.

(d) If the pump is required to operate at maximum efficiency but the flow rate is not important, find the rotational speed at which the pump should be operated and the energy consumed by the pump in delivering 100 m^3 of water.

Q10.
A variable-speed pump lifts water from a reservoir to an elevated tank. The difference in water levels between the reservoir and the tank is 25 m. The pipe between them has length $L = 1.2$ km, diameter $D = 200$ mm and friction factor $\lambda = 0.02$. Minor losses can be neglected. The characteristics of the pump at the operational speed are given in the table below.

Pump characteristics at 2400 rpm

Discharge (L s^{-1})	18	24	30	36	42	48	54	60	66
Head (m)	48.2	47.1	45.5	43.1	39.2	34.5	28.7	22.2	15.2
Efficiency (%)	52.3	61.3	67.9	71.6	72.1	69.1	62.3	51.9	39.1

(a) Find the system characteristic (head as a function of discharge), giving numerical values of the function coefficients and stating the units used for head and discharge.

(b) Find the flow rate and the power consumption at the duty point.

(c) In an attempt to increase the flow rate, the pump speed is increased to 2600 rpm. Find the flow rate and the power consumption at the new duty point.

Q11. (Exam 2023)
A single-speed pump is used to extract water from a flooded basement and deliver it to a detention tank where the water level is 8 m above that in the basement. The pipe is 36 m long and 0.2 m diameter, with friction factor 0.03, and minor losses in the system can be accommodated by a loss coefficient $K = 2.5$. A valve can be used to control the discharge if necessary.

Pump characteristics are given in the following table.

Discharge, Q (L s^{-1})	20	40	60	80	100	120	140
Head, H (m)	33.3	31.7	29.1	25.4	20.6	14.8	7.9
Efficiency, η (%)	19.7	33.8	42.2	45.0	42.2	33.8	19.7

(a) Derive the system characteristic (H vs Q), stating the units that you have chosen to use for H and Q.

(b) Find the maximum discharge in the system, and the input power at this discharge.

(c) If the valve is used to throttle the flow to half the flow rate of part (b), find the loss coefficient for the valve.

(d) If a second, identical pump is used in parallel, find the maximum pumping rate and the total input power required.

Q12. (Exam 2024)
The installation of an experimental flume in a new university engineering building necessitates the pumping of water from ground level up to a header tank, the water-level change being 11 m.

The delivery pipe has length 150 m, diameter 0.18 m and a friction factor of 0.024. Minor losses due to pipe fittings can be accommodated by a minor loss coefficient $K = 6.0$.

A variable-speed pump is to be used for this task. The pump characteristics at 1400 rpm are given in the table below.

Flow rate, Q (m^3 s^{-1})	0.01	0.03	0.05	0.07	0.09	0.11	0.13
Head, H (m)	18.9	17.5	15.6	13.1	10.0	6.44	2.28
Efficiency, η	0.155	0.369	0.471	0.478	0.406	0.274	0.099

(a) Derive the system characteristic (head required as a function of flow rate), giving numerical coefficients and the units used for head and flow rate.

(b) Find the time taken to deliver 25 m^3 of water, and the total energy input to the pump during that time, if:
(i) the pump is operated at 1400 rpm;
(ii) the pump speed is adjusted to operate at its maximum efficiency.

Q13.
A small centrifugal fan is being used to supply air to a laboratory test rig at approximately normal atmospheric conditions. When the fan was running at 2950 rpm it was found that the airflow was less than the required value of 0.28 $m^3 s^{-1}$. Tests on the fan showed that, when running at this speed the characteristic was

$$H = 240(1.0 - Q)$$

where H is the pressure difference in mm of water and Q is the discharge in $m^3 s^{-1}$.

It was found that a pressure difference from the fan of $18600\,Q^{1.75}$ N m^{-2} was needed to produce a discharge of Q m^3 s^{-1} through the test rig. Estimate the speed at which the fan should run to provide the required air flow.

Q14. (Based on Massey, 2011)
A centrifugal pump has suction and discharge openings of diameter 150 mm and 100 mm, respectively. When operating at 1400 rpm the discharge is 25 L s^{-1}, the shaft power is 6.5 kW and the piezometric pressure heads on suction and discharge sides are respectively 4 m below and 12 m above atmospheric pressure. Find:

(a) the difference in total head across the pump;

(b) the overall efficiency.

The pump impeller has an outer diameter of 250 mm and effective outlet area of 15000 mm^2. Water enters the impeller without shock or whirl. At outlet the blades are backward-facing, with blade angle 20°. The actual outlet whirl component is 80% of ideal. Find:

(c) the radial component of velocity at outlet;

(d) the whirl component of velocity at outlet;

(e) the manometric efficiency (= ratio of piezometric head across the pump to Euler head; this is a measure of its effectiveness in increasing pressure).

Q15.

In a proposed hydroelectric scheme the output power required is 60 MW. The gross head at the reservoir is 300 m and head lost in the pipeline will not exceed 20 m. It is intended to use a number of Pelton wheels, each with the following characteristics: operating speed 400 rpm; turbine specific speed (units as in Notes) 50.0; overall efficiency 80%; 6 jets; c_v of nozzles 0.97; speed ratio (i.e. bucket velocity / jet velocity) 0.46.

Assuming operation at maximum efficiency, calculate:

(a) the maximum output power per wheel;
(b) the number of wheels required;
(c) the velocities of jets and buckets;
(d) the diameter of each wheel;
(e) the output power per jet;
(f) the quantity of flow per jet;
(g) the diameter of each jet;
(h) the hydraulic efficiency if the buckets deflect water through 165° and reduce the relative velocity by 15%.