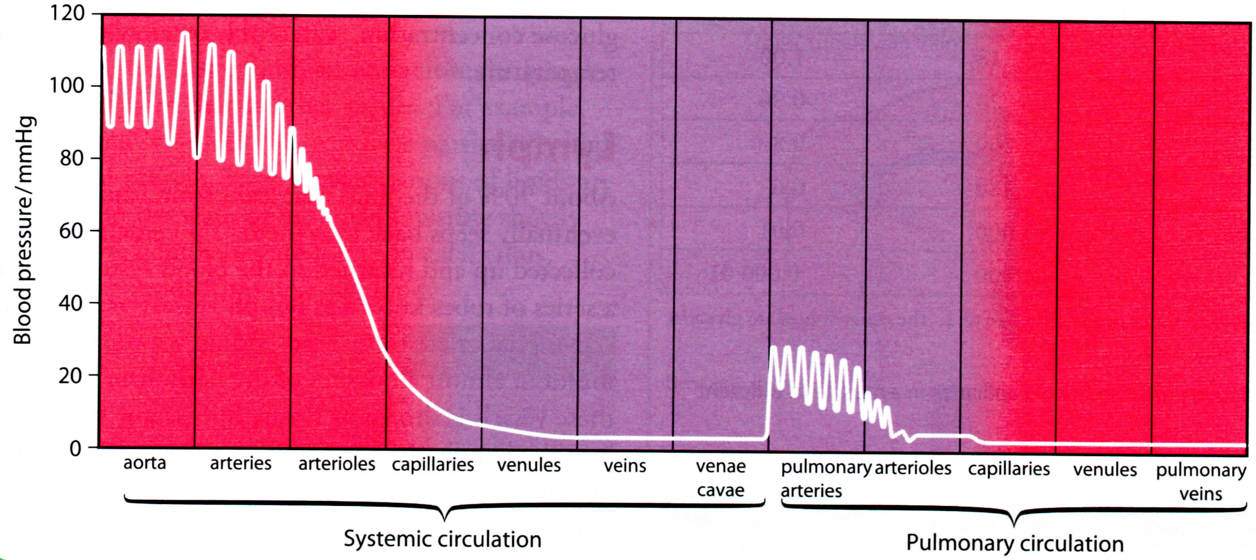

Figure 8.8 Blood pressure in different regions of the human circulatory system.

SAQ 8.4

Suggest reasons for each of the following.

a Normal venous pressure in the feet is about 25 mm Hg. When a soldier stands motionless at attention, the blood pressure in his feet rises very quickly to about 90 mm Hg.

b When you breathe in, that is when the volume of the thorax increases, blood moves through the veins towards the heart.

SAQ 8.5

Using Figure **8.8**, describe and explain how blood pressure varies in different parts of the circulatory system.

Blood plasma and tissue fluid

Blood is composed of cells floating in a pale yellow liquid called **plasma**. Blood plasma is mostly water, with a variety of substances dissolved in it. These solutes include nutrients such as glucose and waste products such as urea that are being transported from one place to another in the body. Solutes also include protein molecules, called **plasma proteins**, that remain in the blood all the time.

As blood flows through capillaries within tissues, some of the plasma leaks out through the gaps between the cells in the walls of the capillary, and seeps into the spaces between the cells of the tissues. Almost one-sixth of your body consists of spaces between your cells. These spaces are filled with this leaked plasma, which is known as **tissue fluid**.

Tissue fluid is almost identical in composition to blood plasma. However, it contains far fewer protein molecules than blood plasma, as these are too large to escape easily through the tiny holes in the capillary endothelium. Red blood cells are much too large to pass through, so tissue fluid does not contain these, but some white blood cells can squeeze through and move freely around in tissue fluid. Table **8.1** shows the sizes of the molecules of some of the substances in blood plasma, and the relative ease with which they pass from capillaries into tissue fluid.

The volume of fluid which leaves the capillary to form tissue fluid is the result of two opposing pressures. Particularly at the arterial end of a capillary bed, the blood pressure inside the capillary is enough to push fluid out into the tissue. However, we have seen that water moves by osmosis from regions of low solute concentration (high water potential) to regions of high solute concentration (low water potential) (page 75). Since tissue fluid lacks

Substance	Relative molecular mass	Permeability
water	18	1.00
sodium ions	23	0.96
urea	60	0.8
glucose	180	0.6
haemoglobin	68 000	0.01
albumin	69 000	0.000 01

The permeability to water is given a value of 1. The other values are given in proportion to that of water.

Table 8.1 Relative permeability of capillaries in a muscle to different substances.

SAQ 8.6

Use the information in Table **8.1** to answer the following.

a Describe the relationship between relative molecular mass of a substance and the permeability of capillary walls to this substance.

b In a respiring muscle, would you expect the net diffusion of glucose to be **from** the blood plasma to the muscle cells or vice versa? Explain your answer.

c Albumin is the most abundant plasma protein. Suggest why it is important that capillary walls should not be permeable to albumin.

the high concentrations of proteins that exist in plasma, the imbalance leads to osmotic movement of water back into capillaries from tissue fluid. The net result of these competing processes is that fluid tends to flow **out** of capillaries into tissue fluid at the **arterial** end of a capillary bed and **into** capillaries from tissue fluid near the **venous** end of a capillary bed. Overall, however, rather more fluid flows out of capillaries than into them, so that there is a net loss of fluid from the blood as it flows through a capillary bed.

Tissue fluid forms the immediate environment of each individual body cell. It is through tissue fluid that exchanges of materials between cells and the blood occur. Within our bodies, many processes take place to maintain the composition of tissue fluid at a constant level, to provide an optimum environment in which cells can work. These processes contribute to the overall process of **homeostasis**, that is the maintenance of a constant internal environment, and include the regulation of glucose concentration, water, pH, metabolic wastes and temperature.

Lymph

About 90% of the fluid that leaks from capillaries eventually seeps back into them. The remaining 10% is collected up and returned to the blood system by means of a series of tubes known as **lymph vessels** or **lymphatics**.

Lymphatics are tiny, blind-ending vessels, which are found in almost all tissues of the body. The end of one of these vessels is shown in Figure **8.9**. Tissue fluid can flow into the lymphatics through tiny valves which allow it to flow in but not out.

The valves in the lymph vessel walls are wide enough to allow large protein molecules to pass through. This is very important because such molecules are too big to get into blood capillaries, and so cannot be taken away by the blood. If your lymphatics did not take away the protein in the tissue fluid between your cells, you could die within 24 hours. If the protein concentration and rate of loss from plasma are not in balance with the concentration and rate of loss from tissue fluid, there can be a build-up of tissue fluid, called **oedema**.

The fluid inside lymphatics is called **lymph**. Lymph is virtually identical to tissue fluid; it has a different name

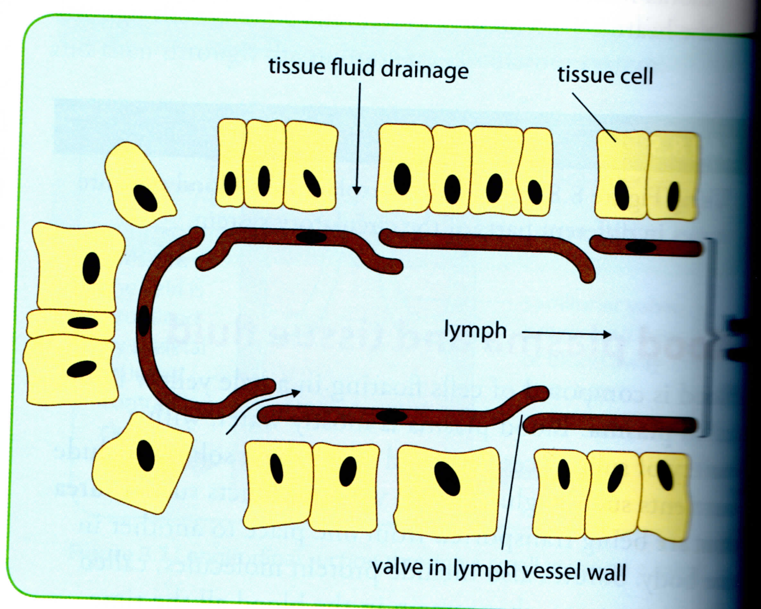

Figure 8.9 Drainage of tissue fluid into a lymph vessel.

more because it is in a different place than because it is different in composition.

In some tissues, the tissue fluid, and therefore the lymph, is rather different from that in other tissues. For example, the tissue fluid and lymph in the liver have particularly high concentrations of protein. High concentrations of lipids are found in lymph in the walls of the small intestine shortly after a meal. Here, lymphatics are found in each villus, where they absorb lipids from digested food.

SAQ 8.7

a We have seen that capillary walls are not very permeable to plasma proteins. Suggest where the protein in tissue fluid has come from.

b The disease kwashiorkor is caused by a diet which is very low in protein. The concentration of proteins in blood plasma becomes much lower than usual. One of the symptoms of kwashiorkor is oedema. Suggest why this is so. (You will need to think about water potential.)

Lymphatics join up to form larger lymph vessels, which gradually transport the lymph back to the large veins which run just beneath the collarbone, the **subclavian veins** (Figure **8.10**). As in veins, the movement of fluid along the lymphatics is largely caused by the contraction of muscles around the vessels, and kept going in the right direction by valves. Lymph vessels also have smooth muscle in their walls, which can contract to push the lymph along. Lymph flow is very slow, and only about 100 cm^3 h^{-1} flows through the largest lymph vessel, the thoracic duct, in a resting human. This contrasts with the flow rate of blood, of around 80 cm^3 s^{-1}.

At intervals along lymph vessels, there are **lymph nodes**. These are involved in protection against disease. Bacteria and other unwanted particles are removed from lymph by some types of white blood cells as the lymph passes through a node, while other white blood cells within the nodes secrete **antibodies**. For more detail, see Chapter **13**.

Blood

You have about 5 dm^3 of blood in your body, with a mass of about 5 kg. Suspended in the blood plasma, you have

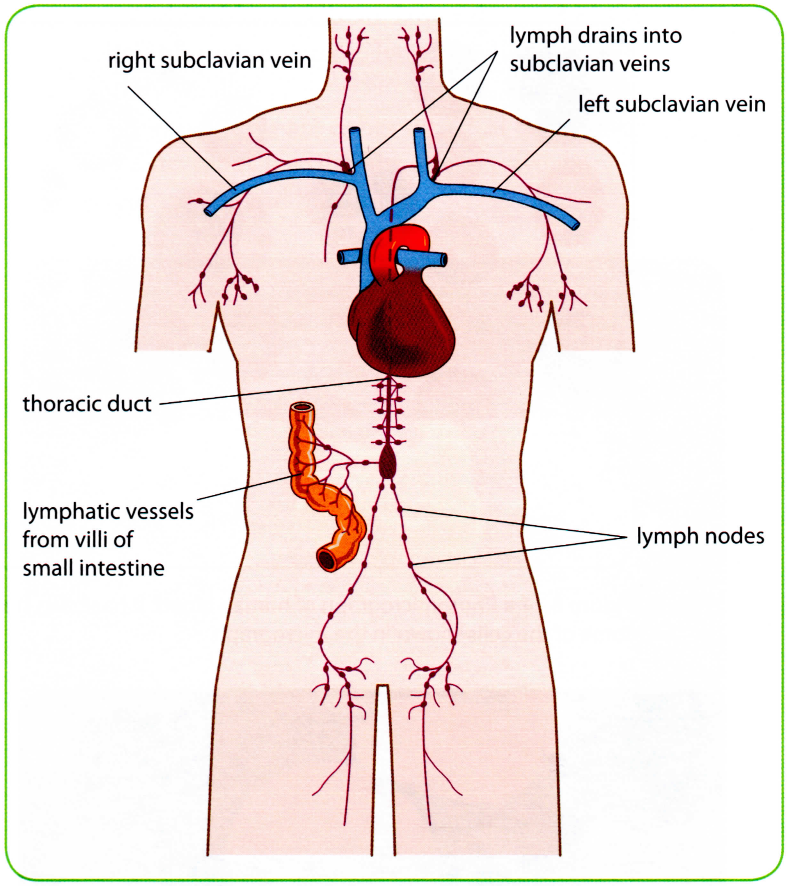

Figure 8.10 The human lymphatic system.

around 2.5×10^{13} red blood cells, 5×10^{11} white blood cells and 6×10^{12} platelets (Figures **8.11** and **8.12**).

Red blood cells

Red blood cells (Figure **8.13**) are also called **erythrocytes**, which simply means 'red cells'. Their red colour is caused by the pigment **haemoglobin**, a globular protein (see page **43**). The main function of haemoglobin is to transport oxygen from lungs to respiring tissues. This function is described in detail on pages **154–156.**

A person's first red blood cells are formed in the liver, while still a fetus inside the uterus. By the time a baby is born, the liver has stopped manufacturing red blood cells. This function has been taken over by the bone marrow. This continues, at first in the long bones such as the humerus and femur, and then increasingly in the skull, ribs, pelvis and vertebrae, throughout life. Red blood cells do not live long; their membranes become more and more fragile