7. *Sand castles and mud huts*

Pack wet sand into a small bucket, press it down firmly, then invert the bucket on the top of the castle. Give the bucket a little shake and lift it gently. You have a turret to support a flagpole. Until the tide comes in, of course, or until the sand dries out. *Dry* sand is useless as a building material. It turns to powder and slides down into a heap, unlike clay or mud which as they dry get harder. Millions of people live in houses made of dried mud.

Why is there this difference between sand and clay?

Let us simplify a little, and say that sand is silica (silicon dioxide, SiO_2). This is a good simplification. Although there will be impurities in the sand – which turn it to the usual golden colour – they make no difference to the theory. The SiO_2 lattice is an extended covalent lattice, with each silicon atom covalently bonded to four oxygen atoms, and each oxygen to two silicons (fig 1).

What happens at the edge of the crystal? Perhaps some of the silicon atoms are only bonding to three oxygens; in other words, they have empty spaces in their orbitals. When the crystals get wet, water molecules may use these vacancies to bond to the surface of the silica crystals (fig 2).

These water molecules can then hydrogen bond to other water molecules (fig 3) thus holding the grains of sand together, and enabling you to build your castle. When the water evaporates, there is nothing left to hold the sand crystals together and they fall apart.

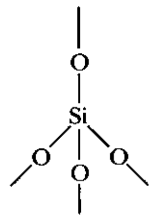

FIG 1

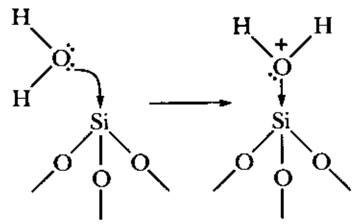

FIG 2

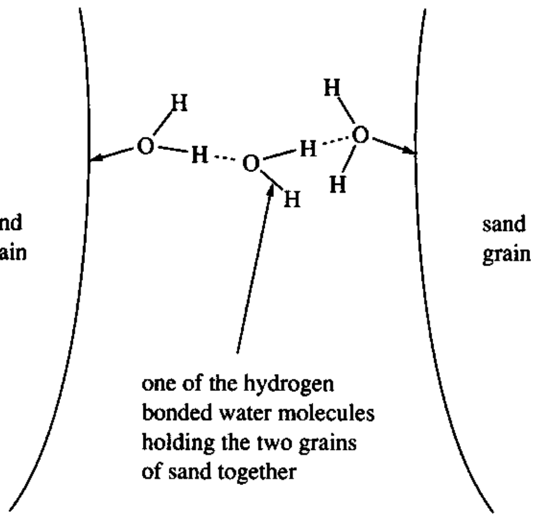

FIG 3

To make a good sand castle, the sand must be wet – but not too wet, or the sand just settles to the bottom of the bucket. Because the sand grains are very irregular in shape, the hydrogen bonding must be irregular, and so it isn't strong enough to bind much water in the spaces between the grains of sand. Indeed, the sand particles will be virtually touching. They will be close-packed, like marbles in a bag, or the atoms in a metal lattice.

CONTINUED

Questions

On atomic structure and intermolecular forces

1. (a) Give the electronic configurations of silicon and oxygen.

(b) Explain how silicon and oxygen bond.

(c) Why does silicon bond to four oxygen atoms, but oxygen to only two silicon atoms?

(d) What is meant by 'an *extended* covalent lattice'?

(e) Explain why the silicon atoms 'have empty spaces in their orbitals'.

2. Explain:

(a) why water molecules are polar, and

(b) how they hydrogen bond to each other, for example, in ice.

3. (a) What does the symbol '→' mean in fig 2?

(b) How many electrons does the silicon atom have before and after bonding to the water molecule? How is this possible?

4. (a) If pure silicon dioxide is added to pure water, the pH of the water falls. Can you explain this, starting from fig 2?

(b) If the particles of silica are quite big, the pH of the water falls very little. But if the silica particles are very small, the pH can drop below 5. Why?

5. Suggest why:

(a) a wet beach is firm to walk on,

(b) a sand castle doesn't shrink as it dries.

Clays are chemically more complicated, and there is a vast range of different ones. Kaolinite, $Al_4(OH)_8Si_4O_{10}$, is one of the simplest. Just as with silica, there are incompletely bonded atoms at the surface of the clay particle. When the clay gets wet, the water molecules will interact with the clay surface just as they did with the sand grains. There are two differences, however.

First, the clay particles are much smaller: with a length of, say, 10^{-8} to 10^{-7} m, compared to 10^{-3} or 10^{-4} m for sand. This means that the clay particles have a much larger surface area. Many more atoms are therefore on the surface of the clay crystals, so there are *many more water molecules attached*.

Second, whereas the sand particles are an irregular spherical shape, the clay particles are more regular, and flat, like plates (fig 4). So the hydrogen bonding can be more regular than in wet sand. The water molecules are therefore held more strongly, and so more of them can be held between the clay particles than between sand particles. Because there is more water, the particles in clay can be loosely packed. So wet clay can be deformed easily by pressure, because there is so much water that the clay particles can slip over one another.

Wet clay shrinks as it dries, until it reaches a certain water content, when the volume stays roughly constant. This is presumably because the wet clay holds so much water that the particles aren't touching, and shrinkage occurs until they do. In order to move the particles in dried clay you have to break many hydrogen bonds. And because these hydrogen bonds are regular you have to break them *all at once*. This will

CONTINUED

clearly be much harder to do than to break the fewer hydrogen bonds in sand, one by one. (It's rather like undoing a zip fastener by pulling it apart, compared to opening it from the end.)

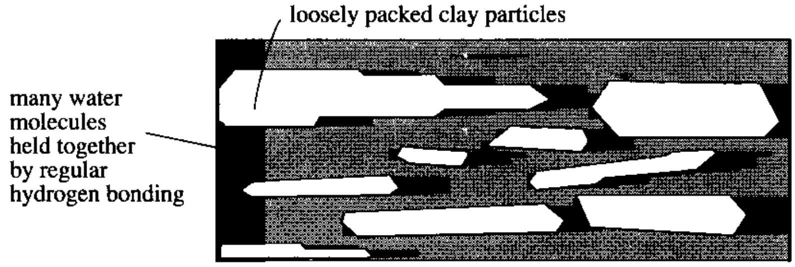

FIG 4

Questions

6. (a) If you walk across wet clay, your feet sink in. A potter can shape the wet clay by pressing it with his hands. How are these things possible?

(b) Wet sheets of glass, such as microscope slides, stick together very strongly, but they are quite easy to *slide* apart. Why?

7. Fig 5 shows the volume of a sample of kaolinite as it was completely dried in an oven.

(a) Why does the volume fall?

(b) If the clay is left to dry in air, rather than in an oven, the water loss *stops* when the water content has fallen to about 16%. Why do you suppose this is so?

(c) What is the significance of this 16% of water?

(d) Why is dry clay hard and strong? In other words why can clay particles stick together in a way that sand particles can't?

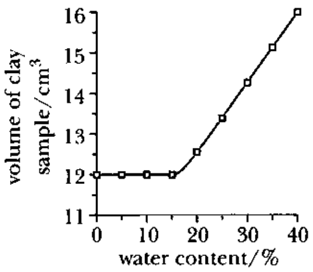

FIG 5

8. Some clays, for example bentonite, form *thixotropic* mixtures with water. A bentonite-water mixture (containing only 0.05% bentonite) forms a jelly-like substance which won't pour out of a test tube even if you turn it upside down. If you give the tube a sharp tap, the mixture becomes completely liquid. On standing it becomes solid again.

(a) Suggest how thixotropy arises. Why will a bentonite-water mixture form a jelly, turn to a liquid if tapped sharply, then reform the jelly on standing?

(b) Some paints ('non-drip') are thixotropic. Why is this property useful?