(b) The can is not crushed. It appears to cool slowly and when cooled contains about a quarter-can of water. The fact that some water is sucked into the can agrees with the hypothesis. The fact that the can is not crushed as before shows that, at best, the hypothesis is insufficient and, at worst, is on the wrong track.

[Ideal answer: Heat transfer within a gas is a slow process dependent mainly on convection. The hot air cools relatively slowly and therefore, the volume decreases slowly. As the volume decreases slowly, so does the pressure inside the container. The higher atmospheric pressure on the outside slowly pushes some water inside the can. There is no water vapour to quickly condense and suddenly change the volume of the gas. The (ideal) hypothesis is supported.]

(c) According to the original hypothesis, the ice water should produce the most significant crushing of the can and the warm water should produce less of an effect than the original cold water. These predictions are based on the cooling of the can — most with ice water, least with warm water.

[Ideal answer: Because the crushing is caused by the condensation of the water vapour, there will likely be little difference when using ice water or warm water because both of these are significantly cooler than 100°C.]

(d) For both the ice water and hot water from the tap, the can was crushed in much the same way as it was originally. Observation of the cans did not show any obvious differences in the cans. The predictions appear to be falsified and again the hypothesis appears to be unacceptable.

[Ideal answer: The evidence appears to agree with the prediction and the (ideal) hypothesis is supported.]

9.1 STATES OF MATTER

ACTIVITY 9.1.1 MOLECULAR MOTION

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Procedure

- Step 2: The shape and volume of the sample remain relatively constant. Individual spheres jiggle slightly while remaining in roughly the same location.
- Step 3: Some individual spheres bounce away from the main group and return. The average volume stays relatively constant. Individual spheres jiggle around more rapidly and randomly. The sample does not stay uniform. Spheres move around with occasional spaces created, which disappear quickly.
- Step 4: The volume of the sample is now the volume of the square container. Individual spheres move in straight lines until they collide with each other or the sides of the container. The spheres are all separated from each other and the spacing between the spheres is many times the size of the spheres.

Analysis

(a) The plastic spheres are placed in a watch glass like a shallow bowl. Gravity forces the spheres to the bottom, or lowest, point. This simulates the attractive forces among particles.

(b) The degree of order or organization, from greatest to least, is solid (Step 2), liquid (Step 3), and then gas (Step 4). Disorder (lack of order or organization) is most apparent with the gas model.

Synthesis

(c) The model works best for gases and reasonably well for solids and liquids. The primary molecular motion of gas molecules is translational and this is clearly shown. Vibrational motion is shown for solids and liquids. There is little evidence of rotation but this may just be hard to see when the spheres are projected. The model works reasonably well for a substance increasing in temperature and changing in phase from solid to liquid and then to gas.

A drawback of the model is the representation of relative molecular speeds among phases of matter at the same temperature. To make the physical model work, the spheres have to move faster (i.e., at a higher temperature) to model a gas rather than a liquid. Evidence indicates that this isn't so for molecules of, say, a gas compared to a liquid for substances at the same temperature.

(d) Diffusion could be shown by introducing a few different-coloured or -sized spheres into the mixture and watching the movement of these spheres relative to the rest of the spheres present. Compressibility of gases could be shown by adding a movable barrier (e.g., a piece of wood dowelling) and decreasing the size of the container available in which the spheres can move.

PRACTICE

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Understanding Concepts

1. In order of increasing strengths of forces among particles, the states of matter are gas, liquid, and solid. Maintaining a specific shape and volume (as a solid does) requires particles to be held close together in fixed positions. Maintaining a specific volume, but not shape (as a liquid does) requires particles to be held close together, but not in fixed positions, so forces are less effective. Dispersing spontaneously (as a gas does) means that particle motion overcomes the effect of any attractive forces.
2. Solids have the highest degree of order, and gases the lowest. Order is directly related to strength of attraction between particles.
3. (a) According to our model of gases, gases are compressible because they consist of individual particles separated by large distances. Pressure can easily force the particles closer together.
   (b) (Typical answer) Why are there spaces between gas particles? Because they have too much energy for the very weak attractive forces between particles to be able bring them together.
   (c) (Typical answer) Why do the particles have a lot of energy? Because they are moving very fast. Why do they move very fast? Because they collide elastically, without losing energy. Why do they collide elastically? Hmmm....

Making Connections

4. (a) Liquids are nearly incompressible, so sealed liquid systems (such as hydraulic lifts) transfer forces very well.
   (b) A gas bubble in a brake line is compressible, preventing the total force from transferring to the brakes.

Reflecting

5. The most common student answer is that visual aids and analogies are the most effective models, particularly when a physical model that can be manipulated is involved. Most students will agree that a variety of models is better than a single example for understanding — sometimes because it makes the understanding more complete, and sometimes because there is only one model that is comprehensible to the students.

SECTION 9.1 QUESTIONS

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Understanding Concepts

1. (a) Atomic combinations make metallic (metal with metal), ionic (metal ion with nonmetal ion), molecular (nonmetal atom with nonmetal atom), or network covalent (bonded elements along the staircase line) substances.
   (b) The bond types between particles in the substances are, in order: metallic, ionic, intermolecular (London dispersion, dipole–dipole, and hydrogen), and covalent bonds.
   (c) A solid state results when attractive forces between particles of a substance are strong enough to hold the particle in place, even for relatively high kinetic (motion) energy. Kinetic energy depends on temperature, while attractive force depends on the structure of the particles and the distance between them.
2. (a) Both are incompressible, because their particles are close together.
   (b) Particles in liquids are free to change position, while those in solids are not. This is because the attractive forces between particles in liquids are not strong enough to stop this translational particle motion, and in solids they are.
3. (a) Attraction between particles in gas phases is negligibly small.
   (b) The prediminant motion for gas particles is translational (place-to-place) motion.

4.

State	Properties	Explanations
solid	solids have definite shape and volume	the attractive force(s) between particles is sufficiently high to hold the particles in place
	are virtually incompressible	the particles are too close together to be compressed
	do not flow easily	the attractive force(s) between particles holds the particles in place
liquid	liquids assume the shape of the container but have a definite volume	attractive forces have been overcome so the particles can rotate and roll over each other and assume new shapes but maintain the same volume
	are virtually incompressible	the particles are still “touching each other” (repelling each other, electrostatically)
	flow readily	the particles can roll over each other
gas	gases assume the shape and volume of the container	the particles are independent of each other due to very small attractive forces; the particles are only contained by the container, not by intermolecular attractions
	are highly compressible	the distance between the particles is large relative to the size of the particle (20–30 times the diameter), so there is empty space for compression
	flow easily	there is little or no attractive force(s) among the particles, so they are free to move independently in any direction

Making Connections

5. Gas particles move very rapidly, so the flexible fabric air bag fills in an instant, before the motorist hits the steering wheel of the car. Gases have no definite shape, so the flexible bag can mould to the motorist’s shape and spread the restraining force evenly. Gases can move through small openings, so the gas from an air bag quickly diffuses through small holes to deflate the bag after a collision, freeing the motorist.

9.2 GAS LAWS

Try This Activity: A Simulation of Gas Properties

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(a) The order of gas cylinders from most likely to least likely to explode is 1, 5, 3, 2, 4. The order is based on the reasoning that smaller volumes and higher temperatures (for the same mass of gas) produce greater pressures. The higher the pressure, the more likely the cylinder will be to explode.
– Cylinder 1 has the smallest volume and the highest temperature and, therefore, should be at the highest pressure.
– Cylinder 5 is also at the highest temperature but has a greater volume than 1. Cylinder 5 has twice the volume of 3, but 5 has a temperature that is almost three times larger. Therefore, 5 likely has a higher pressure than 3.
– Cylinder 3 follows 5, as indicated above, but precedes 2 because 3 has a higher temperature and the same volume as 2.
– Cylinder 2 is at the same temperature as 4 but 2 has a smaller volume. Therefore, the pressure in 2 should be greater than in 4.
– Cylinder 4 has the greatest volume and the lowest temperature, and therefore, the least pressure.
Note: At this stage students would not know about the Kelvin temperature scale. Although the above reasoning is correct, the comparisons should be done using Kelvin, not Celsius, temperatures. If Kelvin temperatures are used, the order of 5 and 3 would likely be reversed.

(b) Variables that need to be considered are the amount of gas, and the volume, temperature, and maximum pressure for the cylinder.

