

## K&S Review Questions

1. While a diamond is much harder than a steel knife, the knife is tougher than the diamond. Explain the difference between hardness and toughness, and why the diamond is more likely to break than the knife when the two collide.
2. Suppose you have two wooden blocks that are identical except that one is 5 times as tall as the other. If you stack the two blocks and then stand on the pair, why will the taller block lose 5 times as much height as the shorter block?
3. If you stack a rubber block on top of a steel block of the same size and then stand on the pair, the rubber block will lose much more height than the steel block. Explain this result in terms of the Young's moduli of the two materials.
4. A flagpole bends in the wind. If the wind pushes 5 times as hard on the flagpole, it will bend 5 times as far. Explain this effect in terms of shear stress and shear strain.
5. As we'll see in the next section, glass is unable to undergo slip. How does the absence of slip in glass contribute to its brittleness?
6. How does annealing a piece of iron soften it and prevent it from experiencing brittle fracture?
7. How does heating and rapidly quenching carbon-rich steel make it hard and brittle?
8. Hardening the steel of a car would make it wonderfully resistant to minor dents but would make it dangerous in a collision. Why is softer steel safer than harder steel in the body and frame of a car?
9. Why does forming tiny metal carbide crystals in steel make that steel harder?
10. Adding chromium and nickel to steel turns it into soft, corrosion resistant stainless steel. What change occurs in the metal's crystal structure that leaves it soft and unsuitable for heat treatment hardening?
11. Why are cheap 18-8 stainless steel utensils so soft and flexible, and why can't the manufacturer use heat treatments to make them stiffer?

## K&S Exercises

1. An inexpensive screwdriver is made from a piece of thick low-carbon steel wire. After this wire is stamped into shape at room temperature by a huge press, a plastic handle is attached and the finished screwdriver is packaged for sale. How does the structure of its steel allow this screwdriver to deform so easily when you try to tighten a screw?
2. A good screwdriver is made from a piece of medium-carbon steel rod. This rod is too hard to stamp into shape at room temperature (see Exercise 1), so it's either shaped at high temperature or cut with an abrasive grinder at room temperature. How does the structure of its steel allow this

screwdriver to resist deformation when you tighten a screw?

3. A premium quality screwdriver is heat treated (see Exercises 1 & 2). While its tip is given an extremely hard surface that won't deform as it twists a screw, its shaft is made tough so that it won't break under stress. How must the screwdriver be heat treated to give it these properties? Explain.
4. A can opener and the can it opens are both made of steel. Explain why the opener cuts the can rather than the reverse.
5. Some fireplaces have soft, low-carbon steel linings. The instructions for one of these fireplaces warn you not to let hot coals and ashes build up against its lining because that will make the lining hard and brittle. How does trapping heat and carbon-rich coals near the lining make it brittle?
6. A tooth has a hard layer of enamel surrounding a softer core of dentin. Why is this composite tooth more durable than one that's solid enamel or solid dentin?
7. Thieves have been known to use liquid nitrogen to break locks. A lock will dent without breaking if you strike it with a hammer at room temperature, but it may shatter if you first cool it to  $-196^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) with liquid nitrogen. Why does cooling the lock change its behavior so dramatically?
8. At room temperature, a bell made of lead is soft. If you strike it with a mallet it just dents. But if you first cool it with liquid nitrogen, it will ring beautifully when you hit it. It also won't dent. Why does cooling the metal make it harder?
9. Some dump trucks have extra wheels that are lowered onto the pavement when the truck is carrying a very heavy load. How do these extra wheels reduce the chance that the truck will cause plastic deformation of the roadway?
10. A theft protection bar bolts to a car's steering wheel and makes the wheel difficult to turn. How does case hardening make the bar both difficult to cut and difficult to break?
11. Steel furniture often breaks at welds, where the metal was heated briefly to its melting temperature in order to join separate pieces together. Why is the welded area of the steel harder and more prone to fracture than the rest of the steel?
12. The body of an aluminum can is formed out of a flat disk of aluminum by working it at room temperature. How does this shaping process strengthen the finished can?
13. Pure gold (24 carat) is generally too soft for jewelry. Alloys such as 14 carat and 18 carat are much harder. Why?
14. Steel drums are traditionally made from the tops of 55 gallon oil drums. The steel of an oil drum is soft and is easily worked into the proper shape for a steel drum. Before the metal will emit tones, however, it must be treated with

heat and carbon. How does this treatment alter the metal?

15. The surface of a hardwood floor bends slightly when you step on it but immediately returns to its original shape. When you drop a pointed object on the floor, however, it dents permanently. Explain these two responses to stress.

16. The Young's modulus of diamond is approximately four times that of iron. If you stack a small cube of iron on top of a similar cube of diamond and press down on the stack, which cube will compress more? How much more?

17. Soft low-carbon steel and hard high-carbon tool steel have virtually identical Young's moduli. If you stack a small cube of low-carbon steel on top of a similar cube of tool steel and step on them, how will the strains they exhibit compare?

18. If soft low-carbon steel and hard high-carbon tool steel have equal Young's moduli (see Exercise 17), why can the tool steel cut through the low-carbon steel so easily?

19. Pure aluminum is too weak for structural use. Most aluminum building materials have a few percent copper, magnesium, or silicon added to the aluminum. Why?

20. Oxygen-free high-conductivity copper is nearly pure copper and an excellent conductor of electricity. When this metal has been annealed carefully, its crystals are enormous and it's so ductile that it can be squeezed through tiny holes to make electric wires. But while a thick bar of this metal is easy to bend the first time, if you straighten it and bend it over and over again it gradually becomes stiffer. Explain this effect.

21. After bending a bar of soft copper until it becomes stiff (see Exercise 20), what can you do to make it soft again?

22. Scientists have recently been able to fabricate metals with grains containing only a few thousand atoms each. These "nanocrystalline materials" are much harder than the normal metals from which they're prepared. Why?

23. The twist ties used to seal plastic food bags can only be used a few dozen times before they break. How does the repeated bending of the metal in the tie cause it to break?

24. Before drawing a steel bar through a narrow opening to make steel wire, the bar is heated to a high temperature and then cooled extremely slowly. Why does this heat treatment make the wire drawing procedure easier?

25. Magnetic wall strips can hold sharp stainless steel kitchen knives but not cheap 18–8 stainless steel knives. Why won't the 18–8 stainless steel knives stick to the strip?

26. Machine tools such as drill bits are made from high-carbon and alloy steels. Their edges are heat treated to give them enormous yield strengths and no capacity for plastic deformation. How does the microscopic structure of the edge make it resist deformation so well and shatter rather than bend when it's over-stressed?

27. The steel used to make springs is hardened to stop plastic deformation. Why is plastic deformation bad for a spring?

28. The solid–solid phase transition that occurs in iron when heated ferrite converts to austenite isn't unique. Many crystals rearrange as they are heated or cooled

through certain temperatures. If the density of the new crystal structure is very different from that of the old crystal structure, the crystal may shatter as it rearranges. Why?

## W&G Review Questions

1. Compare the arrangement of atoms in a salt crystal with the arrangement of atoms in molten salt.

2. Compare the arrangement of atoms in a glass window with the arrangement of atoms in molten glass.

3. Very pure water can be cooled a few degrees below its normal freezing temperature, 0° C (32° F), without solidifying. Explain this effect.

4. As glass cools below its freezing temperature, there's a range of temperatures at which the glass can devitrify—form large crystals. Above or below this temperature range, there's no danger of devitrification. What occurs in this temperature range that makes devitrification possible?

5. When moisture from the air forms frost on a cold window, you can see that it's composed of large crystals that meet at random angles. Explain this structure in terms of crystal nucleation and growth.

6. How do stiff, directional covalent bonds make it easier for materials to form glasses?

7. Why is silicon dioxide so good at forming glasses?

8. Why does adding a chemical that forms ionic bonds soften glass?

9. Why is glass cookware made from glasses with small coefficients of volume expansion?

10. Why is tempered glass so hard to break?

11. Why can't glass be cut to size after being tempered?

## W&G Exercises

1. Many candies are made by boiling a mixture of sugar and water. When only a little water remains, the mixture is cooled rapidly and forms a clear, uniform material that resembles window glass. If the cooling is done too slowly, the mixture turns into damp sugar granules. How do the sugar molecules arrange themselves in these two cases?

2. When candy is cooled too slowly and turns into damp sugar granules (see Exercise 1), it becomes translucent rather than clear. Why?

3. When transparent glass is cooled too slowly through its freezing temperature, it becomes translucent or white. What happens inside the glass to cause this change in appearance?

4. Glass-ceramics are inhomogeneous materials consisting of tiny ceramic crystals in glass. Even if none of the materials in a glass-ceramic absorb light, the glass-ceramic appears translucent or white rather than clear. Why?

5. Scientists continue to search for ways of producing amorphous or glassy aluminum metal. This metal can be as

light as normal aluminum but as strong as steel. Why is glassy aluminum harder than normal crystalline aluminum?

6. The asphalt used to bind gravel together in roadway paving is an amorphous solid at room temperature. What part does asphalt's glass transition temperature play when a road is being built out of hot asphalt and gravel?

7. Ice cream is stirred during freezing to prevent large ice crystals from forming. Another way to form smooth ice cream is to freeze it very quickly by immersing it in liquid nitrogen. Why does this rapid cooling technique prevent large crystals from forming?

8. While honey can remain a liquid for long periods of time, it eventually crystallizes. You can return it to liquid form by heating it. But you must make sure that all the crystals are gone or it will quickly crystallize again. Why?

9. Streams of bubbles rise to the surface of a mug of soda. These bubbles form when carbon dioxide gas comes out of solution in the soda. But carbon dioxide molecules don't join together often enough on their own to start the bubbles. Instead, bubbles usually form at defects on the inside of the mug and rise upward from those defects. How is the difficulty of bubble formation in soda related to the effects that allow glasses to form?

10. People preparing electron microscope samples shave them into incredibly thin sheets with knives made of diamond or glass. While knives made of crystalline diamond remain sharp indefinitely, glass knives must be freshly prepared since they gradually lose their atomic-scale sharpness even without being used. Explain this spontaneous loss of sharpness in a glass knife.

11. There are conflicting opinions about why the glass windows in some ancient European cathedrals are thicker at their bottoms than at their tops. While some people think that this merely reflects the difficulty early glass makers had in producing glass of uniform thickness, others suggest that the glass has slowly shifted downward over the years. Explain why it's possible for glass to shift downward in certain circumstances and why such a downward shift is almost certainly not responsible for the thickening observed in the cathedral windows.

12. Taffy doesn't freeze as you cool it—it just gets stiffer and stiffer until it's rigid. How can the taffy become rigid without there being a particular temperature at which it freezes from a liquid to a solid?

13. Because a crystal tends to contain only a single chemical, chemists frequently purify chemicals by crystallizing them. To avoid trapping impurities in a rapidly growing crystal, they use conditions where crystal growth is slow. Under these conditions the crystals often won't start growing on their own and the chemists must add a few impure crystals to start the crystallization. Why won't the crystals start growing on their own?

14. Some high quality stainless steel sinks are coated underneath with a type of rubber that exhibits lots of internal friction. How does this rubber coating affect the sound the sink emits when you drop a spoon in it?

15. Why does an ice cube usually crack when you take it directly from the freezer and drop it into a glass of water?

16. A board makes a simple bridge across a stream. If you overload the board, it will begin to crack. Why will the crack first appear on the bottom surface of the board?

17. Why isn't tempered glass used in the windows of the armored cars used to deliver money to banks?

18. Why do recyclers ask you not to mix glass cookware with glass bottles and jars?

19. A diamond can be reshaped by cleaving it—exposing it to severe shear stress along a particular plane so that it undergoes brittle fracture. If done properly, the fracture occurs along a plane of atoms and is almost perfectly smooth. If you try this technique with a piece of glass, you won't end up with a smooth fracture. Why not?

20. A tempered glass cup is remarkably hard to break. If you drop it onto a tile floor, it may bounce rather than break. But if its bouncing causes it to scrape hard against the sharp edge of a tile, or even a grain of sand, the cup will crumble into tiny pieces. Explain this behavior.

21. A Bologna bottle is a peculiar version of tempered glass. It's a thick glass bulb that was heated until soft and then cooled rapidly from its outside in. The last portion of the bottle to cool through the glass transition temperature was its inner surface. While the bottle's outer surface is strong enough to hammer in nails, the bottle's inner surface is extraordinarily fragile. The slightest injury to that surface will tear the bottle apart. Why is the inner surface so fragile?

22. The sprinkler systems that protect public buildings from fire release water when pieces of metal inside them melt. This metal melts at about 74° C (165° F), well below the melting temperature of most metals. How is it possible to make a metal that melts at such a low temperature?

23. The glass used to make lenses for cameras and eyeglasses is cooled extremely slowly after it solidifies. Why would more rapid cooling reduce the glass's optical quality?

24. Glass that's under stress is birefringent, responding differently to horizontally and vertically polarized light. Because of its birefringence, stressed glass can partially or completely convert light of one polarization into the other. Use this information to explain why the tempered rear windows of some cars exhibit colored blotches when you look through them at the blue sky while wearing polarizing sunglasses.

25. A glassblower can shape heated glass in endless ways to create works of art. Why isn't this craft possible with normal solids such as salt?

26. When a glassblower is finished forming a piece of glass artwork, the piece should be allowed to cool slowly in an oven. Why?

## P Review Questions

1. Except at very low temperatures, polymers are less brittle than crystalline solids. Explain their resistance to fracture.

2. What role do entanglements play in establishing the rubbery plateau regime of a thermoplastic polymer?
3. Polymers in the rubbery flow regime can become longer and longer if you stretch them slowly, but they respond elastically to sudden intense stress. Why?
4. List three cases in which water acts as a plasticizer for a natural polymer, making that polymer softer.
5. Why is a bicycle tire essentially one giant molecule?
6. Natural rubber is firm and elastic in cold weather. Why does it become sticky in warm weather?
7. Why don't logs melt when you put them in a fire?
8. Why is Teflon so chemically inert?
9. Why does rubber stretch so much more than Kevlar?

## P Exercises

1. Styrofoam coffee cups are made from a frothy mixture of polystyrene and gas. Which of the five regimes is polystyrene in at room temperature? at the temperature of hot coffee?
2. Polystyrene is a clear plastic. Why is Styrofoam white?
3. Starch is a digestible natural polymer that's very similar to cellulose. If you mix starch with a little water you'll find that it behaves very strangely. If you stir it slowly it will behave as a liquid, but if you poke it suddenly with your finger it will feel very hard. Explain this behavior in terms of entanglements and reptation.
4. Dental floss is a strong polymer thread that's used to clean between teeth. Is this polymer above or below its glass transition temperature ( $T_g$ ) at room temperature and how would the floss behave if it were on the other side of  $T_g$ ?
5. When you inflate a balloon and then let the air out of it, it returns to its original shape. When you inflate a piece of bubble gum and then let the air out of it, it just sags. Explain these different behaviors.
6. Some cheap plastic measuring cups are made out of amorphous polystyrene, which has a glass transition temperature of about 100° C (212° F). What would happen to such a cup if you put 120° C (248° F) cooking oil into it?
7. A rubber cooking spatula will scorch if you touch it to a very hot pan, but it will not become soft or sticky. Why not?
8. A glue gun heats a rod of leathery thermoplastic and squeezes the softened plastic onto the pieces being glued together. Once the glue cools, it bonds the pieces together tightly. Describe how this process works in terms of the five regimes of polymer behavior.
9. A good way to keep the end of a nylon rope from unraveling is to melt it together. Why doesn't that technique work for an elastic cord made from strands of vulcanized rubber?
10. A Splat ball is made from an extremely soft silicon polymer. If you throw it against a wall it spreads out into a pancake as though it were liquid, but it gradually pulls itself back together into a sphere. What regime is the polymer in and is it a thermoplastic or a thermoset?
11. Why does vinyl upholstery tend to crack in very cold weather?
12. If you apply latex interior house paint to a damp basement wall, the moisture in that wall will still be able to escape into the air. How does it get through the paint?
13. Some drugs are administered in sealed plastic patches that are applied to the skin. How do the drug molecules get through one of these plastic patch?
14. The more mobile the atoms of a polymer are, the more easily gas molecules can diffuse through that polymer. Use this information to explain why balloons made of rubber (an elastic thermoset) lose helium faster than those made of Mylar (an amorphous thermoplastic with a glass transition temperature well above room temperature).
15. The plastic cup covers provided by fast food restaurants often have buttons you can push to indicate a cup's contents. When you push the button, you bend the glassy plastic and it turns white. Why?
16. Your fingernails are made of a glassy semitransparent polymer called keratin. If you bend your nail too far, it turns white. What causes this sudden color change?
17. The adhesive on the back of a postage stamp is a polymer that softens when you lick it and hardens when it dries out. What is the role of water in changing the behavior of this polymer?
18. Hair is made from a protein polymer that dissolves a moderate amount of water. Why is it so much easier to shave wet hair than dry hair?
19. Wet hair is much limper than dry hair. Hair is made from a protein polymer that dissolves a moderate amount of water. Why is wet hair relatively limp?
20. Woods such as ash can be softened and bent by exposing them to hot, wet steam. Why is the cellulose in ash wood normally rigid and why does heat and moisture make it relatively flexible?
21. It's important to wet a paper tissue before cleaning plastic eyeglass lenses since wet paper is softer than dry paper. Paper is made from cellulose. Why does water soften paper?
22. Poly(vinyl chloride) is a glassy plastic at room temperature, so plasticizers are added to it to produce the soft, leathery vinyl used in notebook covers. If you leave one of these notebooks pressed against a xerographic copy, lettering from the copy will stick to the notebook. Explain.
23. Pure concrete is brittle. But when Kevlar fibers are added to the concrete, it becomes much stronger. How do the Kevlar fibers strengthen the concrete?
24. Pure vulcanized rubber is both flexible and elastic. To keep some rubber tires from stretching when they are inflated, belts of Kevlar fibers are built into them. Why don't the Kevlar belts simply stretch along with the rubber?
25. Silicon rubber flying disks are great for dogs because they're nearly indestructible. They're made from a silicon thermoset that has a glass transition temperature of about -100° C (-148° F). A normal Frisbee is a thermoplastic with

*a glass transition temperature above room temperature. Why is the silicon rubber disk so much less brittle than a normal Frisbee?*

**26.** *Rayon is a form of cellulose fiber. Why do clothes made of rayon shrink when you launder them in water?*

**27.** *Spectra is a polyethylene fiber in which all of the polyethylene molecules have been drawn out so that they are almost perfectly straight. Why is cord made from this material so much stronger than normal polyethylene cord?*