18.2 Which of the following processes are spontaneous and which are nonspontaneous?
(a) dissolving table salt in hot soup – spontaneous
(b) climbing Mt. Everest – nonspontaneous
(c) spreading fragrance in a room – spontaneous
(d) separating helium and neon from a mixture – nonspontaneous

18.4 Define entropy. What are the units of entropy?
Entropy is a measure of the randomness or disorder in a system. Its units are J/mol·K or J/K.

18.5 How does the entropy of a system change for each of the following processes?
(a) A solid melts – increases S
(b) A liquid freezes – decreases S
(c) A liquid boils – increases S
(d) A vapor is converted to a solid – decreases S
(e) A vapor condenses to a liquid – decreases S
(f) A solid sublimes – increases S
(g) Urea dissolves in water – increases S

18.10 Arrange the following substances (1 mole each) in order of increasing entropy at 25°C and describe each substance to explain:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Ne(g)</td>
<td>a monatomic gas with more e− than H₂.</td>
</tr>
<tr>
<td>(b) SO₂(g)</td>
<td>a polyatomic gas with more e− than Ne.</td>
</tr>
<tr>
<td>(c) Na(s)</td>
<td>ordered, crystalline material.</td>
</tr>
<tr>
<td>(d) NaCl(s)</td>
<td>ordered crystalline material, but with more particles per mole than Na(s).</td>
</tr>
<tr>
<td>(e) H₂(g)</td>
<td>a diatomic gas, hence of higher entropy than a solid.</td>
</tr>
</tbody>
</table>

(c) atomic crystal < (d) ionic crystal < (e) gas w/2 e− < (a) gas w/10 e− < (b) polyatomic gas

18.12 Using the data in Appendix 3, calculate the standard entropy changes for the following reactions at 25°C:

\[ \Delta S^\text{rxn} = \Sigma nS^\circ(\text{products}) - \Sigma mS^\circ(\text{reactants}) \]

(a) \[ \text{H}_2(\text{g}) + \text{CuO}(\text{s}) \rightarrow \text{Cu}(\text{s}) + \text{H}_2\text{O}(\text{g}) \]
\[ \Delta S^\text{rxn} = S^\circ(\text{Cu}) + S^\circ(\text{H}_2\text{O}) - [S^\circ(\text{H}_2) + S^\circ(\text{CuO})] \]
\[ = (1)(33.3 \text{ J/K} \cdot \text{mol}) + (1)(188.7 \text{ J/K} \cdot \text{mol}) - [(1)(131.0 \text{ J/K} \cdot \text{mol}) + (1)(43.5 \text{ J/K} \cdot \text{mol})] \]
\[ = 47.5 \text{ J/K} \cdot \text{mol} \]

(b) \[ 2 \text{Al}(\text{s}) + 3 \text{ZnO}(\text{s}) \rightarrow \text{Al}_2\text{O}_3(\text{s}) + 3 \text{Zn}(\text{s}) \]
\[ \Delta S^\text{rxn} = S^\circ(\text{Al}_2\text{O}_3) + 3S^\circ(\text{Zn}) - [2S^\circ(\text{Al}) + 3S^\circ(\text{ZnO})] \]
\[ = (1)(50.99 \text{ J/K} \cdot \text{mol}) + (3)(41.6 \text{ J/K} \cdot \text{mol}) - [(2)(28.3 \text{ J/K} \cdot \text{mol}) + (3)(43.9 \text{ J/K} \cdot \text{mol})] \]
\[ = -12.5 \text{ J/K} \cdot \text{mol} \]
(c) \( \text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(l) \)

\[ \Delta S^\circ_{\text{run}} = S^\circ(\text{CO}_2) + 2S^\circ(\text{H}_2\text{O}) - [S^\circ(\text{CH}_4) + 2S^\circ(\text{O}_2)] \]

\[ = (1)(213.6 \text{ J/K·mol}) + (2)(69.9 \text{ J/K·mol}) - [(1)(186.2 \text{ J/K·mol}) + (2)(205.0 \text{ J/K·mol})] \]

\[ = -242.8 \text{ J/K·mol} \]

18.13 Without consulting Appendix 3, predict whether the entropy change is positive or negative for each of the following reaction. Give reasons for your predictions.

(a) \( 2 \text{KClO}_4(s) \rightarrow 2 \text{KClO}_3(s) + \text{O}_2(g) \)

Positive entropy change (increase). One of the products is in the gas phase (more microstates).

(b) \( \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{O}(l) \)

Negative entropy change (decrease). Liquids have lower entropies than gases (fewer microstates).

(c) \( 2\text{Na}(s) + 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{NaOH}(aq) + \text{H}_2(g) \)

Positive. Aqueous and gas phases both have higher entropy (more microstates) than liquids and solids.

(d) \( \text{N}_2(g) \rightarrow 2 \text{N}(g) \)

Positive. There are two gas-phase species (more microstates) on the product side and only one on the reactant side.

All parts of this problem rest on two principles. First, the entropy of a solid is always less than the entropy of a liquid, and the entropy of a liquid is always much smaller than the entropy of a gas. Second, in comparing systems in the same phase, the one with the most complex particles has the higher entropy.