FIGURE 10 The salts applied to icy roads are electrolytes. They lower the freezing point of water and melt the ice.

Look at the values given for KCl solutions in **Table 3.** The freezing-point depression of a 0.1 *m* KCl solution is only 1.85 times greater than that of a nonelectrolyte solution. However, as the concentration decreases, the freezing-point depression comes closer to the value that is twice that of a nonelectrolyte solution.

The differences between the expected and calculated values are caused by the attractive forces that exist between dissociated ions in aqueous solution. The attraction between the hydrated ions in the solution is small compared with those in the crystalline solid. However, forces of attraction do interfere with the movements of the aqueous ions. Only in very dilute solutions is the average distance between the ions large enough and the attraction between ions small enough for the solute ions to move about almost completely freely.

Peter Debye and Erich Hückel introduced a theory in 1923 to account for this attraction between ions in dilute aqueous solutions. According to this theory, the attraction between dissociated ions of ionic solids in dilute aqueous solutions is caused by an ionic atmosphere that surrounds each ion. This means that each ion is, on average, surrounded by more ions of opposite charge than of like charge. A cluster of hydrated ions can act as a single unit rather than as individual ions. Thus, the effective total concentration is less than expected, based on the number of ions known to be present.

Ions of higher charge attract other ions very strongly. They therefore cluster more and have lower effective concentrations than ions with smaller charge. For example, ions formed by $MgSO_4$ have charges of 2+ and 2–. Ions formed by KCl have charges of 1+ and 1–. Note in **Table 3** that $MgSO_4$ in a solution does not depress the freezing point as much as the same concentration of KCl.

SECTION REVIEW

1. What colligative properties are displayed by each of the following situations?

a. Antifreeze is added to a car's cooling system to prevent freezing when the air temperature is below 0°C.

b. Ice melts on sidewalks after salt has been spread on them.

2. Two moles of a nonelectrolyte solute are dissolved in 1 kg of an unknown solvent. The solution freezes at 7.8°C *below* its normal freezing point. What is the molal freezing-point constant of the unknown solvent? Suggest a possible identity of the solvent.

3. If two solutions of equal amounts in a U-tube are separated by a semipermeable membrane, will the level of the more-concentrated solution or the less-concentrated solution rise?

4. a. Calculate the expected freezing-point depression of a 0.200 *m* KNO_3 solution.

b. Will the value you calculated match the actual freezing-point depression for this solution? Why or why not?

Critical Thinking

5. INFERRING RELATIONSHIPS The freezing-point depressions of aqueous solutions A, B, and C are –2.3°C, –1.2°C, and –4.1°C, respectively. Predict the order of the boiling-point elevations of these solutions, from lowest to highest. Explain your ranking.