### Evaluation

(c) The evidence from the molecular models agrees with the predictions for each central atom. In all cases, except $NH_2OH$, the shape of the whole molecule was predicted. $NH_2OH$ does not seem to have an overall shape because the ends of the molecule can rotate. Therefore, the predictions are generally verified, indicating an adequate understanding of VSEPR theory as it applies to the structure of small molecules. Additional information may be needed to know if there is a preferred orientation of molecules with two or more central atoms which can rotate about a bond axis.

## INVESTIGATION 4.4.1 TESTING FOR POLAR MOLECULES

**(Page 277)**

### Prediction

(a) According to the empirical rules in Table 1, water, ethanol, 1,2-ethanediol, and acetone all have polar molecules because they fall into the category of oxygen and other atoms, or carbon and two other kinds of atoms. Pentane and hexane have nonpolar molecules because they fall into the category of carbon and only one other kind of atom.

### Evidence

(b)

**Testing Liquids with Charged Strips**

| Substance | Chemical formula | Effect of charged strip | |
|---|---|---|---|
| | | Acetate | Vinyl |
| acetone | $(CH_3)_2CO_{(l)}$ | attracted | attracted |
| 1,2-ethanediol | $C_2H_4(OH)_{2(l)}$ | attracted | attracted |
| ethanol | $C_2H_5OH_{(l)}$ | attracted | attracted |
| hexane | $C_6H_{14(l)}$ | no effect | no effect |
| pentane | $C_5H_{12(l)}$ | no effect | no effect |
| water | $H_2O_{(l)}$ | attracted | attracted |

### Analysis

(c) According to the evidence collected, acetone, 1,2-ethanediol, ethanol, and water all have polar molecules because they were all attracted to the charged strips. Hexane and pentane were not attracted. Therefore, they do not have polar molecules.

### Evaluation

(d) The experimental design seems very simple with no obvious flaws. The question was clearly answered. An improvement might be to specify more specifically where the charged strip should be placed. It is also not clear if the strips were charged the same each time. This could be somewhat controlled by rubbing the strip the same number of times each time it is charged. Neither of these should substantially affect the results. If quantitative results are desired, more sophisticated equipment and procedure would be required. Overall, I am reasonably confident with the evidence.

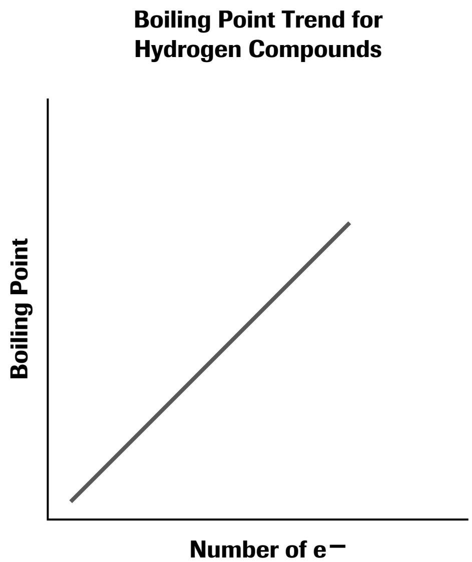
(e) The results clearly agree with the prediction. Therefore, the prediction has been verified and the empirical rules appear acceptable.

## LAB EXERCISE 4.5.1 BOILING POINTS AND INTERMOLECULAR FORCES

**(Page 278)**

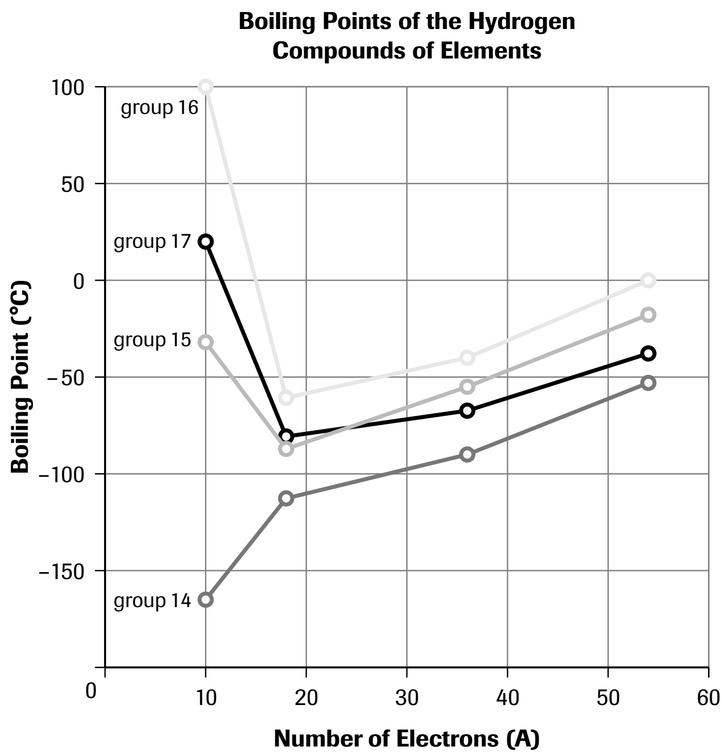
### Prediction

(a) Molecules of the hydrogen compounds of one group will all be similar in shape and polarity (polar versus nonpolar). Therefore, the dipole–dipole forces between molecules for members of the same group should be similar. For example, the Group 14 hydrogen compounds all have symmetrical tetrahedral molecules and therefore should be nonpolar. The other groups have molecules that are all nonsymmetrical and therefore will be somewhat polar, producing some dipole–dipole effects. The only significant difference within a group of hydrogen compounds will be the increasing number of electrons per molecule as you go down the group. Therefore, based on the rule for London forces, the strength of these forces should increase down the group and the boiling points should increase accordingly. This tendency should produce a graph that has the following general trend for each group of hydrogen compounds.




### Analysis

(b)




(c) According to the evidence, the boiling point generally increases with increasing number of electrons, with some obvious exceptions such as $NH_3$, $H_2O$, and HF.

### Evaluation

(d) Three out of the sixteen compounds tested (about 19%) differed substantially from the prediction. For this reason, the prediction is judged to be inconclusive. The rules for intermolecular forces, in particular London forces, remain acceptable, but further tests need to be done to increase the certainty of this evaluation. More families of compounds of Groups 14 to 17 elements need to be investigated, especially compounds of nitrogen, oxygen, and fluorine.

(e) The evidence for $NH_3$, $H_2O$, and HF was an anomaly. It may be that hydrogen compounds of these same elements are exceptions and the London force theory has to be restricted or revised depending on the results of further tests. There may be other forces at work, or perhaps some dipole–dipole forces in the selected compounds are exceptionally strong.