A Cellophane Toy and Its Wrapper

Overview

Students apply the scientific method as they investigate the form and function of the materials used to make this simple toy and its packaging. Part B extends the activity for upper-grade students, as they work to correlate their observations to the chemical structures and FT-IR spectral fingerprints (provided) of these materials.

Key Concepts

- absorption
- evaporation
- experimental design
- hydrophilic substances

National Science Education Standards

Science as Inquiry

Abilities Necessary to Do Scientific Inquiry

- *Students speculate about what causes the movement of the cellophane fish. (5–8)*
- *Students design an experiment to determine which variable has the greatest effect on the behavior of the fish. (5–8, 9–12)*
- *Students develop an explanation based on the results of their investigations. (5–8, 9–12)*
- *In Part B, students compare FT-IR spectral fingerprints for cellulose and polyethylene to understand the correlation of chemical structures with physical properties, spectral data, and commercial applications. (9–12)*

Physical Science

Properties of Objects and Materials

- *The fish is made from cellophane, which attracts water. The wrapper is made of polyethylene, which does not attract water. (5–8)*
- *FT-IR analysis can identify distinguishing characteristics of the materials that comprise the toy fish and its wrapper. (9–12)*

Transfer of Energy

- *Heat energy is transferred from the warmer, body-temperature hand to the cooler, room-temperature fish. (5–8)*

Interactions of Energy and Matter

- *The FT-IR spectra show that different atoms and molecules exhibit peaks at different wavelengths. These peaks can be used to identify a substance. (9–12)*

Science and Technology

Abilities to Do Technological Design

- *Students consider and evaluate the nature of the packaging material used as the wrapper. (5–8)*

Part A: Student Exploration

How does this frisky fish work? Why is it in that wrapper?

Materials

- Fortune Teller Fish in its wrapper
- other materials as needed for the student-designed experiment in step 4, such as
  - source of non-wet, low heat, such as an electric heating pad, hand warmer, or heat pack
  - paper towel
  - water

Procedure

1. Remove the Fortune Teller Fish from its plastic wrapper. Place the fish in the palm of one hand. *What happens? Speculate about what factors might cause this behavior.*
2. Place the fish on a clean, dry table. *What happens? List factors that might cause the difference you observe. Does this change your list of factors from step 1?*
3. Lay the plastic wrapper on your hand. *What happens?* Now put the fish on top of the wrapper on your hand. *What happens?*
4. Experiment to determine which factor has the greatest effect on the behavior of the fish.
5. Now that you've explored the materials used to make this toy fish, imagine that you were the chemist in charge of designing the wrapper for the fish. *What properties or characteristics would be important in making your selection of material?*

Part B: Student Exploration

What's the chemistry of these materials?

Materials

- FT-IR spectrum of the cellulose Fortune Teller Fish (provided)
- FT-IR spectrum of the Fortune Teller Fish wrapper (provided)
- structural formula for cellulose (provided)

Procedure

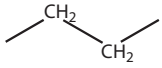
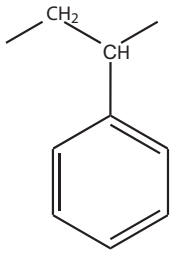
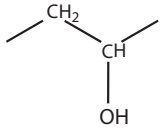
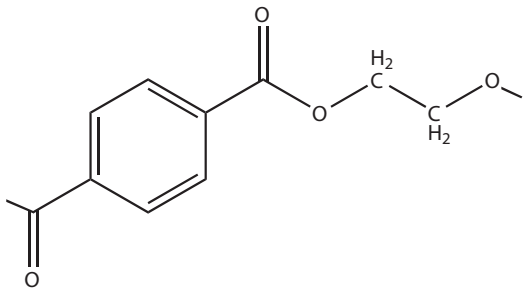
1. To find out about the chemistry of the materials, you're going to look at the chemical structures of the fish as well as the FT-IR (Fourier Transform Infrared) spectra for the fish and wrapper materials. Don't be intimidated by the term FT-IR—while this is a powerful analytical tool that depicts how atoms in a molecule are connected, it can be simply thought of as providing "fingerprints." You'll be using these fingerprints, which can be used to identify different molecules, to find similarities and differences between the materials used to make the fish and its wrapper. (Note that, while your eyes don't "see" infrared light, different plastic films do respond differently to infrared light, creating different FT-IR fingerprints.)

2. The Fortune Teller Fish is made of cellophane, which is principally cellulose, an organic compound that forms the primary cell wall of green plants. For industrial purposes, cellulose is usually obtained from wood pulp or cotton. Look at the FT-IR of cellulose and find the peaks associated with O-H bonding and C-H bonding. Next look for O-H bonding and C-H bonding in the structural formula for cellulose.

3. *What is the chemical structure for water? Do any parts of the cellulose structure appear to be similar to water's structure?* An important concept in chemistry states that substances that are chemically similar to water are attracted to water. *Based on this concept, suggest a reason for the behavior you observed when the fish was exposed to moisture.*

4. *Predict how the FT-IR spectrum of the wrapper might be different from the spectrum of cellulose.* Now look at the spectrum of the wrapper to check your prediction.

5. Table 1 lists the predominant peaks for common materials used in wrappers. *Which of these materials do you think the Fortune Teller Fish wrapper is made from?*

Table 1: Several Polymer Films and Some Observed Infrared Peaks							
Polymer Film	**Repeating Monomer Unit**	**Wavenumbers (in cm^{-1}) of IR Peaks**					
		3300	**3030**	**2950–2850**	**1700**	**1650**	**1450**
polyethylene		No	No	Yes	No	No	Yes
polystyrene		No	Yes	Yes	No	Yes	Yes
polyvinyl alcohol		Yes	No	Yes	No	No	Yes
polyethylene terephthalate		No	Yes	Yes	Yes	Yes	Yes

Instructor Notes

Tips and Instructional Strategies

- On a very humid day, the fish may move even when placed on the table or on the wrapper. But its movement is rarely as great as when in direct contact with a sweaty hand. If the fish gets really water-logged by a sweaty palm, it may continue to move even on the wrapper or table. Because everyone does not sweat the same way, the behavior of the fish will vary from person to person.
- For Part A, step 4, discuss experimental design as a class. Emphasize the importance of controlling variables. Establish what the variables would be for each testable question proposed, and discuss how students would control these variables. Have students perform their experiments, make claims based on the evidence they collect, and report these claims to the class. Allow for a class discussion and have students reformulate their claims based on this discussion.
- If time does not permit students to design their own experiments in Part A, step 4, you can provide guidance by suggesting that they place the fish on top of a non-wet, mild heat source and record their observations. Ask them if heat affects the fish. Then, similarly test the effect of moisture by laying a damp paper towel (with the excess water squeezed out) on the table and placing the fish on the damp towel. (Take care that students do not overly wet the fish or put the fish directly into water, as this could render it useless.) Then, ask students to draw conclusions as to why the fish behaved the way it did.
- After finishing Part A with the students, you have a good opportunity to initiate a discussion of the scientific method. Ask them what they did in Part A (observe, ask questions, make predictions, identify variables, etc.). Ask them what this process is called (scientific method). This activity also illustrates the non-linearity of the scientific method in a way that students may not have been exposed to previously.
- You may want to encourage students to consider the importance of packaging and the chemists who make decisions about how a product is packaged. Packaging chemists consider factors including the protection of the product, cost, environmental impact, size, consumer appeal, and many others.
- Some cellophane is treated so that it does not absorb water. Thus, attempts to make a homemade version of this toy would require cellophane that has not been treated. (You might want to try a PVA water-soluble laundry bag.)
- Older students continue investigating the Fortune Teller Fish and its wrapper in Part B. We suggest making the FT-IR spectra and the chemical structure of cellulose (located at the end of this activity) into overheads to be shared one by one with students. In step 2, as students look at the spectrum for cellulose, help them to understand that the labeled peaks in the spectra indicate that the molecule has O-H and C-H bonds. When students look at the chemical

structure for cellulose, you may have to remind them that in the shorthand of chemical structures, carbons are present at the five points of the rings even though the Cs are not written. This should help the students to identify areas of O-H and C-H bonding in the structure. In step 3, you may need to help students identify the-OH groups in the cellulose structure as being similar to water.

- Introductory information about FT-IR and its uses is available from the California Institute of Technology (published by the Nicolet Thermo Corporation) at *http://mmrc.caltech.edu/FTIR/FTIRintro.pdf.* (The URL is case-sensitive.)

Explanation

The Fortune Teller Fish curls and twists primarily because it absorbs water produced by the sweat glands in the hand and subsequently loses this water through evaporation. The fish is made of cellophane (mainly cellulose), which is hydrophilic. (*Hydro* means "water" and *philic* means "loving.") As water is absorbed, it moves through small pores in the cellophane and evaporates. The lightness of the cellophane makes the fish very susceptible to air currents, which adds to the "dancing" effect.

In Part A, students explore the Fortune Teller Fish and its packaging. When the fish is on the plastic wrapper on the hand, the fish doesn't move as it does on the bare hand. The wrapper is made of polyethylene, which forms a barrier that prevents the cellophane from absorbing water from the hand. Polyethylene (PE) is a polymer commonly used in consumer goods and packaging. It is made by bonding together thousands of ethylene (CH_2=CH_2) monomer units.

FT-IR, or Fourier Transform Infrared, is used to identify unknown materials, determine the quality or consistency of a sample, or to determine the amounts of various components in a mixture. FT-IR involves passing infrared radiation through a sample. As the radiation passes through the sample, some is absorbed by the sample. A plot of percent transmittance versus wavenumber will show dips at the wavenumbers where the IR radiation is absorbed. The FT-IR spectrum for a particular molecule is as individual as a human fingerprint—no two unique molecular structures produce the same spectrum (pattern of percent transmittance versus wavenumber).

Answers to Student Questions

Part A

Step 1

a. *The fish moves, curls, twists, and turns. It kind of looks like it's dancing.*
b. *The fish's movement could be caused by the heat, sweat, or saltiness of skin; lotion, perfume, or cologne; light; static electricity; or other factors.*

Step 2

a. *When put on the table, the fish typically flattens out and stops moving.*

b. The movement of the fish must have been caused by something that is present on the palm of the hand that is not present on the table.

c. Referring back to answer 1b, the light can now be eliminated as a cause, as the light was present in both cases. Possible factors still include heat, sweat, or saltiness of sweat; lotion, perfume, or cologne; or static electricity.

Step 3

a. The wrapper lies flat without any visible change or effect.

b. The fish lies on the wrapper without any visible change or effect.

Step 5

The wrapper should be waterproof, low cost, lightweight, attractive, and have minimal environmental impact.

Part B

Step 3

a. The chemical structure of water is a bent molecule, with oxygen in the center and two O-H bonds. The H-O-H bond angle is 109 degrees, which provides the bent shape.

b. Each cellulose structure has three O-H bonds; two are attached to the rings and one is attached to a carbon attached to the ring. These O-H bonds are similar to the O-H bonds in water.

c. The attraction of water to the cellophane fish caused the bottom side of the fish, on either a sweaty hand or a damp paper towel, to absorb a small amount of water, causing the observed curling.

Step 4

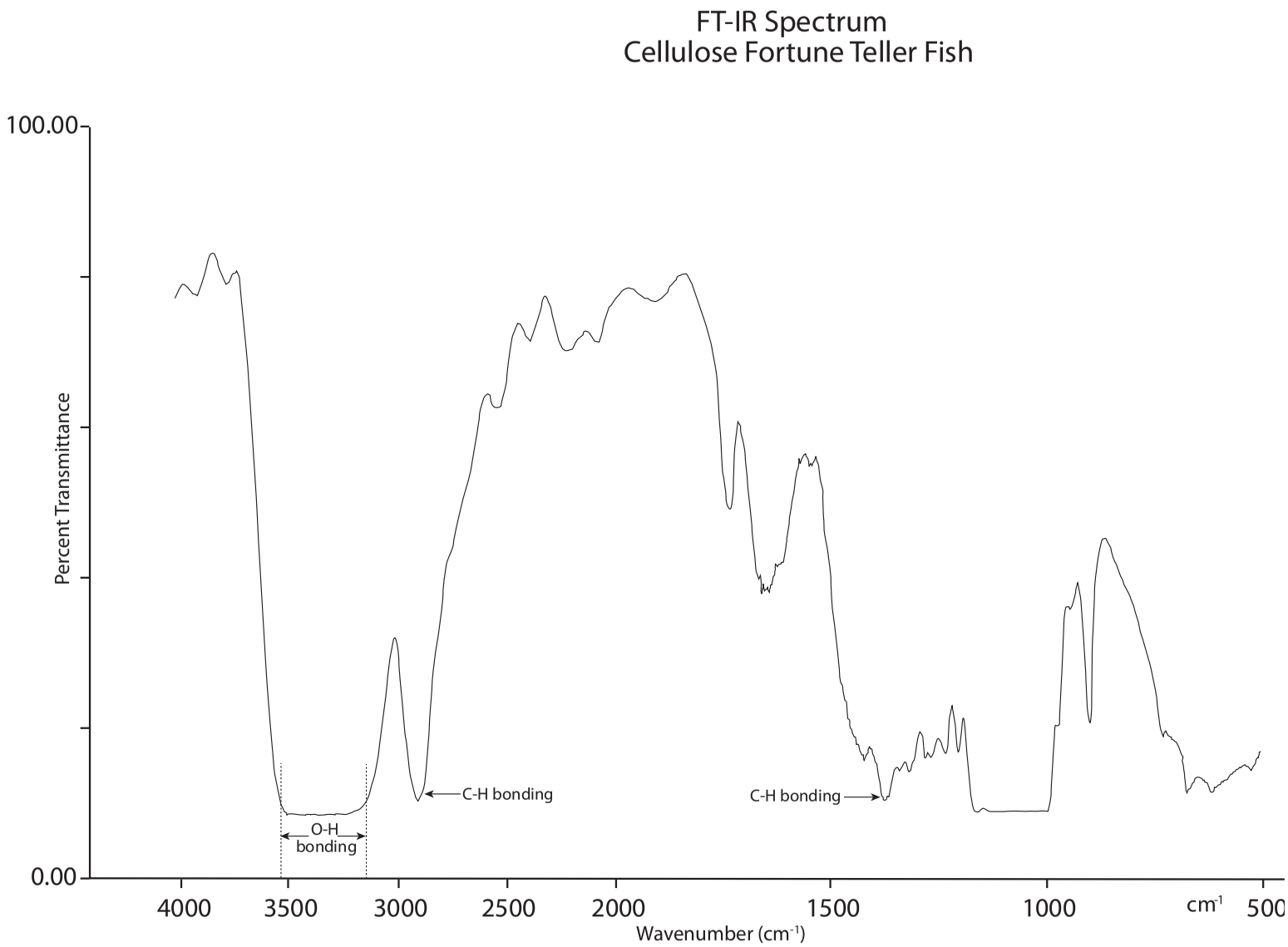
The FT-IR for the wrapper will not show the -OH peaks.

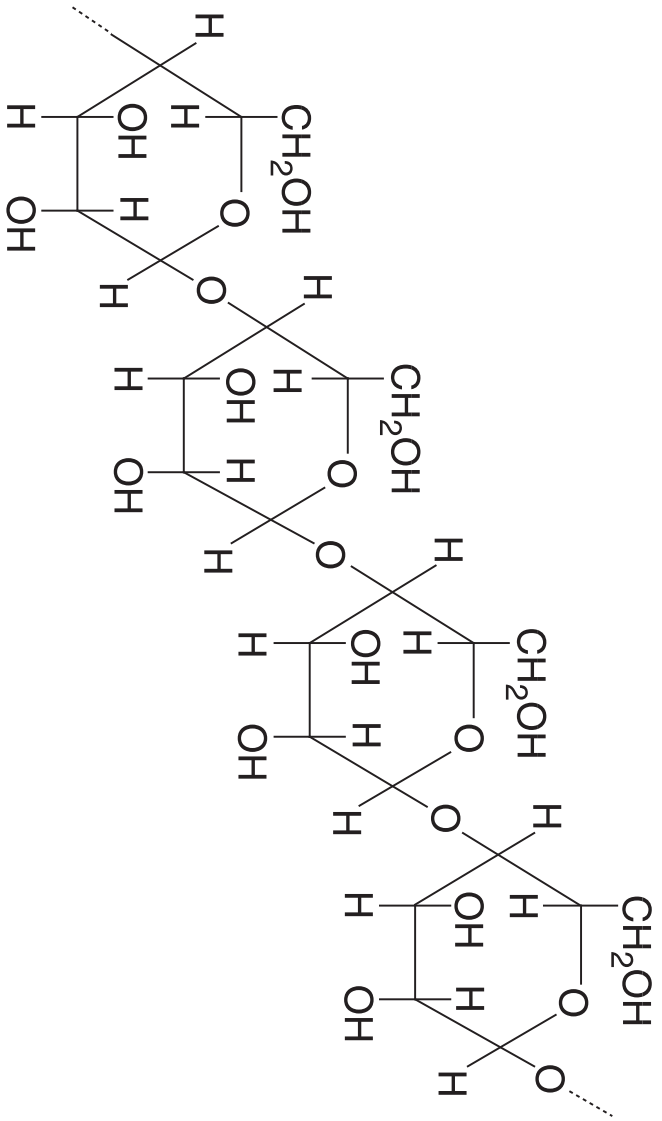
Step 5

The wrapper must be made of polyethylene.

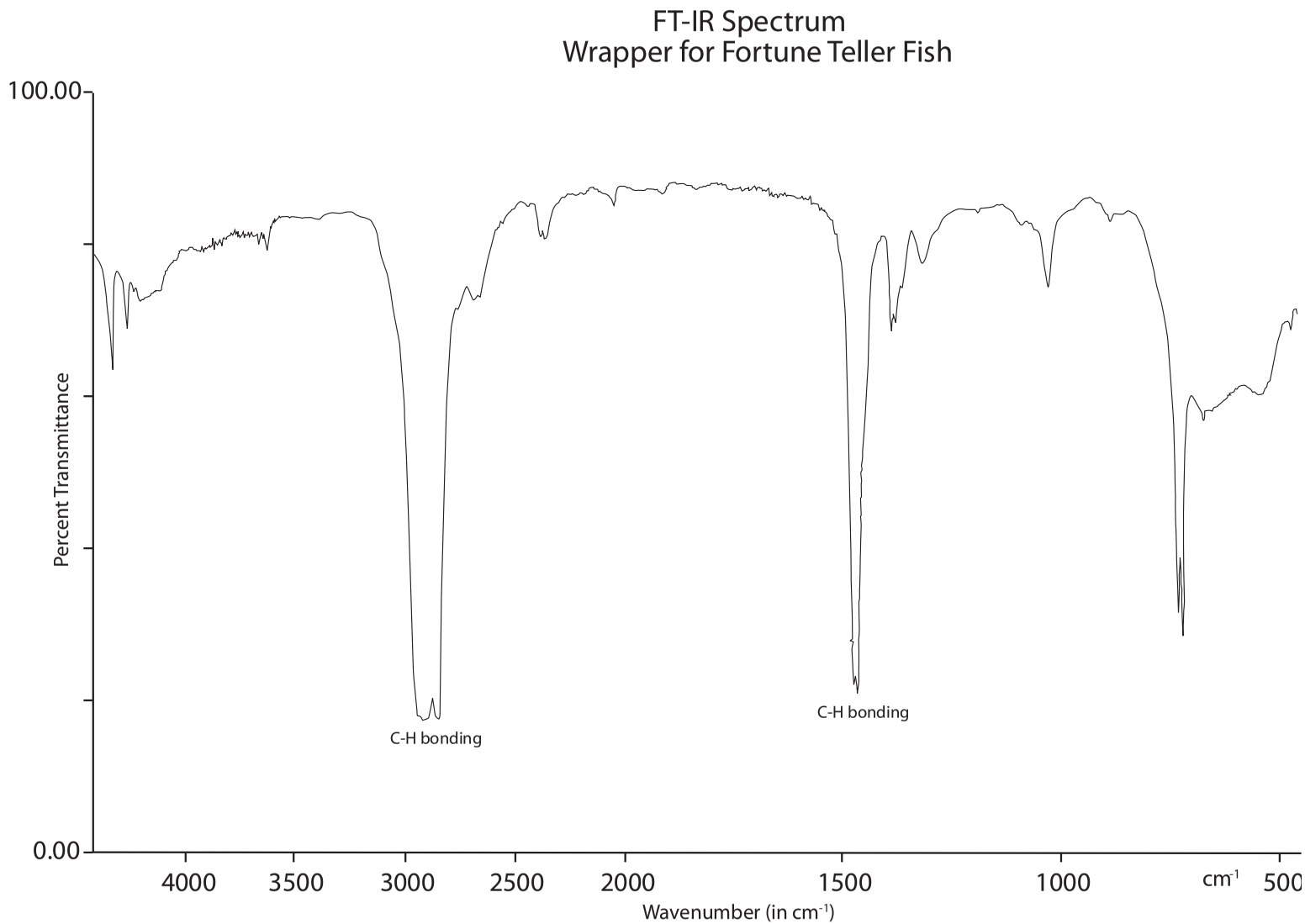
Reference

Thermo Scientific Website. http://www.thermo.com/eThermo/CMA/PDFs/Articles/articlesFile_12268.pdf (accessed Mar 2009), Introduction to Fourier Transform Infrared Spectrometry.


FT-IR Spectrum
Cellulose Fortune Teller Fish
100.00
0.00
Percent Transmittance
O-H bonding
C-H bonding
C-H bonding
4000
3500
3000
2500
2000
1500
1000
cm-1
500
Wavenumber (cm-1)



The structure of cellulose


FT-IR Spectrum
Wrapper for Fortune Teller Fish
100.00
0.00
Percent Transmittance
C-H bonding
C-H bonding
4000
3500
3000
2500
2000
1500
1000
cm-1
500
Wavenumber (in cm-1)