Chapter 1

About Science

THE MAIN IDEA

Science is the study of nature's rules

1.2 An Investigation of Sea Butterflies

Let's consider an example of a recent scientific research project that shows how the scientific method can be put to work. Along the way, we'll get a taste of how chemistry and biology are integrated in the physical world. The Antarctic research team headed by James McClintock, Professor of Biology at the University of Alabama at Birmingham, and Bill Baker, Professor of Chemistry at the University of South Florida, was studying the toxic chemicals Antarctic marine organisms secrete to defend themselves against predators (**Figure 1.3**).

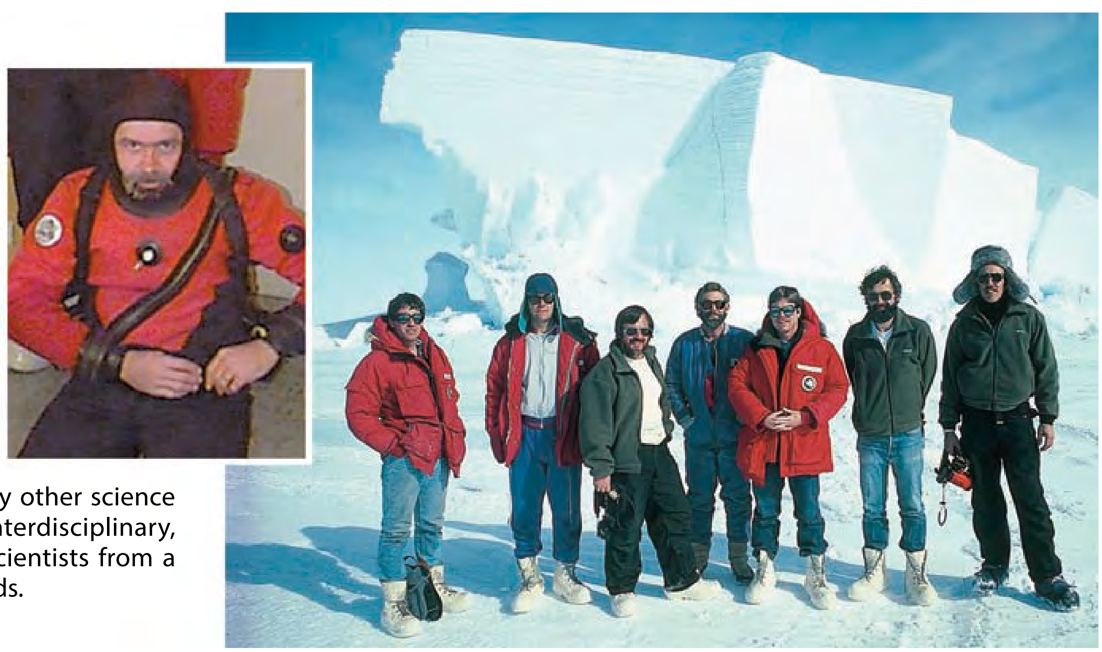
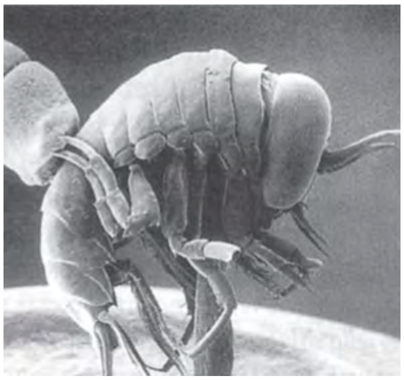


Figure 1.3 >
The Chemical Ecology of Antarctic Marine Organisms Research Project was initiated by James McClintock, shown here (fifth from left) with his team of colleagues and research assistants. He was later joined by Bill Baker (second from right). Baker is shown in the inset dressing for a dive into the icy Antarctic water. Like many other science projects, this one was interdisciplinary, involving the efforts of scientists from a wide variety of backgrounds.


(a)


(b)

Λ Figure 1.4

(a) The graceful Antarctic sea butterfly is a species of snail that does not have a shell. (b) The shrimplike amphipod attaches a sea butterfly to its back even though doing so limits the amphipod's mobility.

McClintock and Baker observed an unusual relationship between two animal species, a sea butterfly and an amphipod. This relatioinship led to: a question, a scientific hypothesis, a prediction, tests concerning the chemicals involved, and finally a conclusion. The research generally proceeded according to the steps of the classic scientific method.

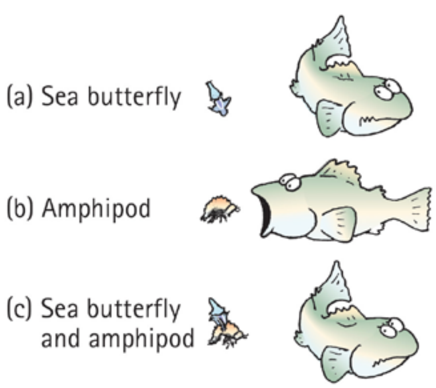
1. Observe. The sea butterfly Clione Antarctica is a brightly colored, shell-less snail with winglike extensions used in swimming (**Figure 1.4a**). The amphipod Hyperiella dilatata resembles a small shrimp. McClintock and Baker observed a large percentage of amphipods carrying sea butterflies on their backs, with the sea butterflies held tightly by the legs of the amphipods (**Figure 1.4b**). Any amphipod that lost its sea butterfly would quickly seek another—the amphipods were actively abducting the sea butterflies!

2. Question. McClintock and Baker noted that amphipods carrying butterflies were slowed considerably, making the amphipods more vulnerable to predators and less adept at catching prey. Why then did the amphipods abduct the sea butterflies?

3. Hypothesize. Given their experience with the chemical defense systems of various sea organisms, the research team hypothesized that amphipods carry sea butterflies to produce a chemical that deters a predator of the amphipod.

4. Predict. Based on their hypothesis, they predicted (a) that they would be able to isolate this chemical and (b) that an amphipod predator would be deterred by it.

5. Test predictions. To test their hypothesis and predictions, the researchers captured several predator fish species and conducted the test shown in **Figure 1.5**. The fish were presented with solitary sea butterflies, which they took into their mouths but promptly spat back out. The fish readily ate uncoupled amphipods but spit out any amphipod coupled with a sea butterfly. These are the results expected if the sea butterfly was secreting some sort of chemical deterrent. The same results would be obtained, however, if a predator fish simply didn't like the feel of a sea butterfly in its mouth. The results of this simple test were therefore ambiguous. A conclusion could not yet be drawn.



Λ Figure 1.5

In McClintock and Baker's initial experiment, a predatory fish (a) rejected the sea butterfly, (b) ate the free-swimming amphipod, and (c) rejected the amphipod coupled with a sea butterfly.

All scientific tests need to minimize the number of possible conclusions. Often this is done by running an experimental test along with a control. Ideally, the experimental test and the control differ by only one variable. Any differences in results can then be attributed to how the experimental test differed from the control.

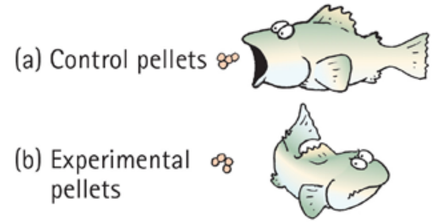
To confirm that the deterrent was chemical and not physical, the researchers made one set of food pellets containing both fish meal and sea butterfly extract (the experimental pellets). For their control test, they made a physically identical set containing only fish meal (the control pellets). As shown in **Figure 1.6**, the predator fish readily ate the control pellets but not the experimental ones. These results strongly supported the chemical hypothesis.

Further processing of the sea butterfly extract yielded five major chemical compounds, only one of which deterred the predator fish from eating the pellets. Chemical analysis of this compound revealed it to be the previously unknown molecule shown in **Figure 1.7**, which they named pteroenone.

6. Draw a conclusion. In addition to running control tests, scientists confirm experimental results by repeated testing. In this case, the Antarctic researchers made many food pellets, both experimental and control, so that each test could be repeated many times. Only after obtaining consistent results in repeated tests can a scientist draw a conclusion. McClintock and Baker were thus able to conclude that amphipods abduct sea butterflies in order to use the sea butterflies' secretion of pteroenone as a defense against predator fish.

Yet, this conclusion would still be regarded with skepticism in the scientific community. Why? There is a great potential for unseen error in any experiment. A laboratory may have faulty equipment that leads to consistently wrong results, for example. Because of the potential for unseen error from any particular research group, experimental results must be reproducible to be considered valid. This means that other scientists must be able to reproduce the same experimental findings in separate experiments. Thus you can see that it is a long road from bright idea to accepted scientific finding! The plodding, painstaking nature of this process is beneficial, though—it is the reason that scientific knowledge is highly trustworthy.

As frequently happens in science, McClintock and Baker's results led to new questions. What are the properties of pteroenone? Does this substance have applications—for example, can it be used as a pest repellent? Could it be useful for treating human disease? In fact, a majority of the medicinals we use were originally discovered in natural sources. This illustrates that there is an important reason for preserving marine habitats, tropical rainforests, and the other diverse natural environments on Earth—they are storehouses of countless yet-to-be-discovered substances.



∧ Figure 1.6

The predator fish (a) ate the control pellets but (b) rejected the experimental pellets, which contained sea butterfly extract.

READING CHECK

Why must experimental findings be reproducible to be considered valid?

∧ Figure 1.7

Pteroenone is a molecule produced by sea butterflies as a chemical deterrent against predators. Its name is derived from ptero-, which means "winged" (for the sea butterfly), and -enone, which describes information about the chemical structure. The black spheres represent carbon atoms, the white spheres hydrogen atoms, and the red spheres oxygen atoms.

CONCEPT **CHECK**

1. What variable did the experimental fish pellets contain that was not found in the control pellets?
2. If the fish had eaten the experimental pellets, what conclusion could the scientists have drawn?

CHECK YOUR ANSWER

1. Sea butterfly extract.
2. The scientists would have had to conclude that the predator fish were not deterred by the sea butterfly secretions and thus that the amphipods did not capture the sea butterflies for this reason.