STUDY GUIDE

for

OXYGEN

By Carl Djerassi and Roald Hoffmann

The authors of the play “Oxygen” have distinguished careers as chemists. And they also have a commitment to reaching out to the general public, each in a distinct way, through essays, books, poems, novels, and plays. “Oxygen” is a play they have written together. The play has been performed in the USA, the UK and Germany, and broadcast over UK and German radio. It has also been published in book form in English, and in German translation, by Wiley-VCH.

The play and the book serve as an excellent introduction to the culture and mores of science and scientists. The nature of discovery, the critical role of competition and priority, the joy and drama of discovery, the role of women in science – these are some of the issues that emerge in a lively, witty play.

We believe “Oxygen,” whether in play or book form, can serve an important educational mission, stimulating interest and debate about the nature of science in young people. To help teachers at both the secondary and university level to present the play to young people, we have written this study guide. It first summarizes the play, and gives an extended description of the main characters (a selection of literature on the protagonists is also included). Then it sets some of the historical background for the events of the play, especially that of an erroneous but plausible chemical theory, phlogiston. And the way the discovery of oxygen played the critical role in the chemical revolution. We also include an essay by one of us on the way science has been portrayed in contemporary theatre. In a final section, we include an introduction to the ethics of scientific research written by one of us, and lead the teacher and students to a bibliography of works on ethics and the culture of science.

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Carl Djerassi and Roald Hoffmann

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of

OXYGEN

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What is discovery? Why is it so important to be first? These are the questions that trouble the people in this play. “Oxygen” alternates between 1777 and 2001—the Centenary of the Nobel Prize—when the Nobel Foundation decides to inaugurate a “Retro-Nobel” Award for those great discoveries that preceded the establishment of the Nobel Prizes one hundred years before. The Foundation thinks this will be easy, that the Nobel Committee can reach back to a period when science was done for science’s sake, when discovery was simple, pure, and unalloyed by controversy, priority claims, and hype….

The Chemistry Committee of the Royal Swedish Academy of Sciences decides to focus on the discovery of Oxygen, since that event launched the modern chemical revolution. But who should be so honored? Lavoisier is a natural choice, for if there ever was a marker for the beginning of modern chemistry, it was Lavoisier’s understanding of the true nature of combustion, rusting, and animal respiration, and the central role of oxygen in each of these processes, formulated in the period 1770-1780. But what about Scheele? What about Priestley? Didn’t they first discover oxygen?

Indeed, on an evening in October 1774, Antoine Lavoisier, the architect of the chemical revolution, learned that the Unitarian English minister, Joseph Priestley, had made a new gas. Within a week, a letter came to Lavoisier from the Swedish apothecary, Carl Wilhelm Scheele, instructing the French scientist how one might synthesize this key element in Lavoisier’s developing theory, the lifegiver oxygen. Scheele’s work was carried out years before, but remained unpublished until 1777.

Scheele and Priestley fit their discovery into an entirely wrong logical framework—the phlogiston theory—that Lavoisier is about to demolish. How does Lavoisier deal with the Priestley and Scheele discoveries? Does he give the discoverers their due credit? And what is discovery after all? Does it matter if you do not fully understand what you have found? Or if you do not let the world know?

In a fictional encounter, the play brings the three protagonists and their wives to 1777 Stockholm at the invitation of King Gustav III (of *Un ballo in maschera* fame). The question to be resolved: “Who discovered oxygen?” In the voices of the scientists’ wives, in a sauna and elsewhere, we learn of their lives and those of their husbands. The actions of Mme. Lavoisier, a remarkable woman, are central to the play. In the Judgment of Stockholm, a scene featuring chemical demonstrations, the three discoverers of oxygen recreate their critical experiments. There is also a verse play within a play, on the Victory of Oxygen over Phlogiston. Such a play, now lost, was actually staged by the Lavoisiers for their friends and patrons.

Meanwhile, in the beginning of the 21st century, the Nobel Committee investigates and argues about the conflicting claims of the three men. Their discussions tell us much about whether science has changed in the last two centuries. The chair of the Nobel Committee is Astrid Rosenqvist, an outstanding Swedish theoretical chemist, while a young historian, Ulla Zorn, serves as a recorder for the committee's proceedings. But with time, her role changes.

The ethical issues around priority and discovery at the heart of this play are as timely today as they were in 1777. As are the ironies of revolutions: Lavoisier, the chemical revolutionary, is a political conservative, who loses his life in the Jacobin terror. Priestley, the political radical who is hounded out of England for his support of the French revolution, is a chemical conservative. And Scheele just wants to run his pharmacy in Köping, and do chemical experiments in his spare time. For a long time, he—the first man on earth to make oxygen in the laboratory—got least credit for it. Will that situation be repaired 230 years after his discovery?

CAST OF CHARACTERS

Stockholm, 1777

ANTOINE LAURENT LAVOISIER, 34 years old. (French chemist, tax collector, economist, and public servant; discovered oxygen).

MARIE ANNE PIERRETTE PAULZE LAVOISIER, 19 years old. (Wife of the above).

JOSEPH PRIESTLEY, 44 years old. (English minister and chemist; discovered oxygen).

MARY PRIESTLEY, 35 years old. (Wife of the above).

CARL WILHELM SCHEELE, 35 years old. (Swedish apothecary; discovered oxygen).

SARA MARGARETHA POHL (FRU POHL), 26 years old. (*Became MRS. SCHEELE three days prior to Carl Wilhelm's death*).

COURT HERALD *(off-stage male voice).*

Stockholm, 2001

Prof. BENGT HJALMARSSON, member of the Chemistry Nobel Prize Committee of the Royal Swedish Academy of Sciences. (*Same actor as ANTOINE LAVOISIER*).

Prof. SUNE KALLSTENIUS, member of the Chemistry Nobel Prize Committee of the Royal Swedish Academy of Sciences. (*Same actor as CARL WILHELM SCHEELE*).

Prof. ASTRID ROSENQVIST, chair of the Chemistry Nobel Prize Committee of the Royal Swedish Academy of Sciences. (*Same actress as MRS. PRIESTLEY*).

Prof. ULF SVANHOLM, member of the Chemistry Nobel Prize Committee of the Royal Swedish Academy of Sciences. (*Same actor as JOSEPH PRIESTLEY*).

ULLA ZORN, a graduate student in the History of Science and amanuensis to the Chemistry Nobel Prize Committee. (*Same actress as FRU POHL*).

EXPANDED DESCRIPTION OF HISTORICAL CHARACTERS

ANTOINE LAURENT LAVOISIER, 34 years old. (French chemist, tax collector, economist, public servant, and debunker of mesmerism. Lavoisier was wealthy and self-assured—certain that he was constructing the proper framework for all of chemistry).

ANNE MARIE PIERRETTE PAULZE LAVOISIER, 19 years old. (Born and married into wealth, Mme. Lavoisier was educated to help her husband in his scientific and public endeavors. On one 1794 day she lost her husband and father to the guillotine of the Jacobin terror. She recovered, with effort, his estate, published his science, and in a second, most unhappy marriage was united briefly with an American-British-Bavarian scientist and adventurer, Count Rumford.)

JOSEPH PRIESTLEY, 44 years old. (English minister, political activist, and chemist. Priestley was one of the founders of the Unitarian church, a dissenter in religion and in politics. After teaching at several dissenter academies, he entered the service of Lord Shelburne. Eventually his radical political views led to a mob assault on his home; Priestley fled to the US, where he lived out his life in Northumberland, PA, defending the phlogiston theory to his death. Priestley discovered several gases, including oxygen, nitrous oxide, and carbon monoxide; he also perfected a popular machine for carbonating water.)

MARY PRIESTLEY, 35 years old. (Daughter of the well-know ironmonger John Wilkinson and sister of one of Priestley's students, she married the young minister in 1762 and partook in his academic and religious life. Mary Priestley is said to have written beautiful letters, but none survived the Birmingham fire in which Priestley's laboratory and home were sacked. In 1794 with the help of Benjamin Franklin, the couple and their children settled in America).

CARL WILHELM SCHEELE, 35 years old. (Swedish apothecary, born in a German family in Stralsund, Pomerania, then Swedish. He was early apprenticed to an apothecary, and pursued that calling all his life. A dedicated and skillful experimentalist, he discovered not only oxygen, but chlorine, manganese, hydrofluoric acid, hydrogen sulfide, oxalic and citric acids, and many organic molecules. Scheele also invented a very good green paint containing arsenic that may have contributed to Napoleon's demise. Scheele's dearest wish was to own his own pharmacy and toward the end of his brief life, he achieved that aim in provincial Köping).

SARA MARGARETHA POHL (FRU POHL), 26 years old. (Became MRS. SCHEELE three days prior to Carl Wilhelm's death. Prior to that she had been married to a German pharmacist, Hindrich Pascher Pohl, the father of her only child (who died at 14). The Köping pharmacy eventually was sold to Scheele, and Fru Pohl became his housekeeper. After Scheele's death in 1786, his widow sent some documents to the Royal Swedish Academy of Sciences, among them the draft of Scheele's letter to Lavoisier. She wrote that she gave Scheele the most respectable funeral that Köping had ever seen. She then married a third German pharmacist).

PHLOGISTON*

Roald Hoffmann

Chemistry gone astray, deluded for a hundred years by a false theory, that of phlogiston. Such a convenient set-up for the rationalizing revolution to come at the end of the eighteenth century!

The reality was that of an incorrect but fruitful idea that served well the emerging science of chemistry. At the heart of the theory was fire. This was consistent with the alchemical tradition. And fire differed from the other elements, much as a verb differs from a noun.

Chemistry is the science of molecules (earlier one would say substances) and their transformations. Some of the changes are spontaneous, proceeding under ambient conditions. Some must be driven with an input of energy. Heat is but one form of transforming energy, others being the energy of light absorbed, or electrical energy. But it took another two centuries to recognize these; in the 1600's heat, and its source, fire, seemed the only obvious generative principle -- what was needed to transform wheat into bread, iron ore into steel.

The idea, growing out of the work of Johann Joachim Becher and Georg Ernst Stahl, was that the essence of fire was a substance called phlogiston. When matter burned, it gave off phlogiston. Wood was full of it, ashes empty. Hematite was iron lacking phlogiston. With much fire, much inflow of phlogiston (from coal, rich in the principle), it could be converted to useful iron, which in turn gave off its phlogiston when it rusted. Oxygen itself, when discovered by Priestley (and independently, before him, by Scheele), was termed "dephlogisticated air" because it supported combustion.

Phlogiston theory worked very well, substituting a "not A," or "minus A," wherever there was an A. For burning or rusting, the critical A is oxygen, as Lavoisier realized (though he missed that it could be sulfur or some other element). So rust is not iron minus phlogiston, but a compound of iron and oxygen. And burning is a combination with oxygen, heat and light given off, instead of a loss of phlogiston. As long as one was interested in the overall process, an argument could be shaped on either presence or absence. For instance, the ingenious connection between burning and rusting, not obvious, was made before the oxygen theory appeared.

The standard argument against phlogiston, only made more precise by Lavoisier, was that substances gained weight upon rusting and upon burning (if it was organic matter that burned, you had to realize that a gas, carbon dioxide,

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* This essay is taken from “Chemistry Imagined,” by Roald Hoffmann and Vivian Torrence, Smithsonian Institution Press, Washington, 1993.

was given off, and include that in the mass balance). So how could something, phlogiston, be given off if the weight increased? This did not bother the proponents of the theory as much as we think it should, because they had a holistic picture of chemistry as a science concerned with overall or intrinsic qualities. Weight did not seem to them worth worrying about, not yet. In 1781 Richard Watson wrote: "You do not surely expect that chemistry should be able to present you with a handful of phlogiston, separated from an inflammable body; you may just as reasonably demand a handful of magnetism, gravity or electricity to be extracted from a magnetic, weighty or electric body; there are powers in nature, which cannot otherwise become the objects of sense, than by the effects they produce, and of this kind is phlogiston."

In the end they were wrong. Their theory was replaced by a new language, a new emphasis, in fact concentrating on mass relationships, that worked better. Adherents to the phlogiston theory for a while complained that the new methodology failed to explain, that it substituted measurement without comprehension for a framework of understanding. In a way they were right. But in time the new chemistry took hold, and found, first in the atomic theory and molecular weights, then in the new quantum mechanics, the correct theoretical foundation. But the explainers with fire, heirs to Prometheus, deserve more credit than history affords them.

AIR OF REVOLUTION

Roald Hoffmann*

Two centuries ago the French Revolution shaped a historical exclamation point. It changed the world's perception——of absolute monarchy, of nationhood, of the rights of man. It also coincided, that best of times, that worst of times, with a revolution in chemistry. The French Revolution also affected critically, even mortally, the lives of at least two of the three men who crafted the change in chemistry.

These three were Joseph Priestley, Carl Wilhelm Scheele, and Antoine Lavoisier. The chemical revolution was as complicated and multiform as the French one; to assign it a precise date is as simplistic as to think of the world changing on the day a nearly empty Bastille fell. The components of that chemical revolution were the discovery of oxygen and the true nature of burning, the attendant end of the phlogiston theory, and the essential introduction of precise quantitative measurement in chemistry.

<u>The intellectual setting</u>. A dominant chemical theory of a century's standing, Stahl and Becher's phlogiston. Phlogiston was posited as the principle of fire itself, given <u>off</u> in the process of combustion of any substance. It described well, metaphorically, the spent nature of burnt matter.

<u>Air and burning</u>. The indispensability of air for combustion was well known. There were strong hints that air was a <u>mixture</u> of gases, as hard to believe as that was of that seemingly most homogeneous substance. A candle flame or a live animal exhausted the life-principle of the air after consuming only a fifth of it.

<u>Measurement</u>. Critical by then, indeed a hallmark of astronomy and physics, only slowly perceived as essential to chemical experimentation.

Joseph Priestley was born near Leeds, England, in 1733. He was a religious dissenter. To believe, as he, one of the founders of the Unitarian Church, did, that "... Jesus was in nature truly and solely a man, however highly exalted by God," was not likely to endear him to prevailing Anglican orthodoxy. Nor did his siding with the claims of the American colonists in a contemporary independence struggle, nor his quiet but determined marking of the achievements of the French Revolution, his admiration for the rights of man. Priestley's meeting house was burned by a mob on the second anniversary of Bastille Day in 1791; he fled to America three years later, there to spend the last ten years of his life.

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* This essay is taken from "Chemistry Imagined," by Roald Hoffmann and Vivian Torrence, Smithsonian Institution Press, Washington, 1993.

A latecomer to chemistry, Priestley carried out his scientific experiments at home or at a public brewery nearby. He devised a neat way to heat intensely substances confined to a glass container, by using the lens-concentrated heat of the sun. A red powder, mercurius calcinatus per se (made by heating mercury in air, now known as mercuric oxide, HgO), heated by a burning lens on August 1, 1774, gave off a gas that supported burning and respiration in mice and proved to be the vital component of air. Priestley called it dephlogisticated air (for it encouraged fire, desired phlogiston), but what he had done was to make oxygen.

Priestley published his discovery quickly. This statement describes his attitude toward experimentation and publication: "... when I made a discovery, I did not wait to perfect it by more elaborate research, but at once threw it out to the world, that I might establish my claim before I was anticipated. I subjected whatever came to hand to the action of fire or various chemical reagents, and the result was often fortunate in presenting some new discovery."

Actually the gas had been discovered several years earlier by Carl Wilhelm Scheele. Scheele was born in 1742 in Stralsund, one of the great Hanseatic cities in Pomerania, on the German north coast. The city was still in Swedish hands in that year, nearly a century after it had become Swedish after the Thirty Years War. Scheele, probably German by origin, was apprenticed to an apothecary in Gothenburg at fourteen, and he remained in that calling in Sweden all his life. In much of Europe a pharmacist is called a chemist, testimony to the close historical ties of the two professions. Scheele was a truly wonderful chemist, the discoverer of many acids -- of hydrogen cyanide, hydrogen fluoride and hydrogen sulfide (all of which he sniffed and tasted, no doubt contributing to his untimely death) -- and of the elements manganese, oxygen, molybdenum, and chlorine. However, credit for discovering the elements went elsewhere, an instructive story in each case.

Scheele made oxygen by decomposing a variety of salts, including the same mercuric oxide that served Priestley. He did it, bootlegging time as an apothecary's assistant, one to four years before the English minister did. Scheele called oxygen eldsluft, fire air, or aër nudus, or aër purus. His discovery was well known to the Uppsala community, but in putting it in the written or printed record, Scheele ran into trouble. First he took his time (unlike Priestley) to write a book. Then he faced a procrastinating, unreliable publisher -- nothing new about that. And finally he waited for a tardy preface by an authority, the great Swedish chemist of his time, Torbern Bergman. The book did not appear until summer 1777, two years after Priestley's publication, at least four years after Scheele's discovery. Incidentally, Scheele, like Priestley, was a staunch advocate of the phlogiston theory.

Antoine Laurent Lavoisier was born a year after Scheele. Hardworking and versatile, he brought precise measurement to chemistry. The balance of science, like the balance in the hands of Justice, was to be his instrument -- and not just one balance. Lavoisier had several, each carefully suited to cover a range of weights, each increasing in precision and accuracy. Through a series of careful weighings and experiments that ingeniously isolated the system under study (a diamond in a bell jar, his laboratory assistant in a silk bag, mercury heated to boiling), he showed the indestructibility of matter. Things certainly change, but nothing is lost, nothing created in a chemical reaction.

Priestley came to Paris in October 1774 and told Lavoisier of his experiments making dephlogisticated air. Lavoisier repeated them, made them more precise. He was the first to realize clearly that oxygen was the essential agent in burning; he was also the one who named it "oxygen" (from Greek, meaning "acid former"). Combustion (and respiration) was combination with oxygen, with attendant weight gain. The phlogiston theory, trying to wriggle out of this weight gain by postulating negative mass for the fire-principle, was just untenable -- air would not support it. Lavoisier gave Priestley precious little credit. I suspect that Priestley's discovery (interpreted by Priestley in terms of the faulty phlogiston theory -- the political radical was a chemical conservative) was a small but essential increment to a framework Lavoisier had already been building for some time. He could not quite bring himself, not yet, to articulate his own theory. And then he had difficulty in dealing with Priestley's less systematic discovery that pushed his, Lavoisier's, knowledge past the point of understanding, to daring to express that understanding.

It's interesting to note that Scheele communicated his discovery of oxygen in a personal letter to Lavoisier in early October 1774. It was a competitive science, even then.

Ambitious Lavoisier married Marie Anne Pierrette Paulze de Chastenolles when she was thirteen; she later studied art with J. L. David. There is a striking double portrait by David of M. and Mme. Lavoisier, now in the Metropolitan Museum of Art. Mme. Lavoisier is the dominant figure in the painting. Indeed, she is a remarkable figure in her own right. She illustrated Lavoisier's books and helped him run his laboratory. Eleven years after his death she married another charismatic figure, the American/British/Bavarian adventurer and scientist, Benjamin Thomson, Count Rumford. Through his marriage, Lavoisier came to buy a share in the Ferme Générale, the <u>ancien regime</u> tax collection agency. For that he was guillotined at the age of fifty-one in the terror of 1794. Perhaps the fact that he had earlier publicly exposed as faulty Jean Paul Marat's claims as a scientist also played a part in this tragedy; Marat's indictment of Lavoisier is vicious.

What is the lesson of these three biographies linked by the life-giver oxygen? That science is international? That it depends on human ingenuity that can operate in apothecary shops and breweries? That open communication of new findings is critical? That claims of priority tell us something about human nature, and the essential reproducibility of the underlying facts? That one can do marvelous science within a wrong theoretical framework? All that and, most important, that chemistry is firmly embedded in the context of society. It may wish to isolate itself in glass-glittery laboratories. But the world butts in, at the beginning, in the middle, at the end of life.

Where Scheele worked was determined by a struggle for European power one hundred years before his birth. How he lived (and that he could do chemistry) derived from the rules of the ancient profession of apothecaries. He moved from Gothenburg to Malmö to Stockholm to Uppsala to the hardly cosmopolitan Köping, all in search of a living. He lost (only for a time) his valid claim to have discovered oxygen because of the workings of patronage and the publishing trade.

Priestley spoke for social change, for placing political power in the hands of the people, and saw his scientific work disrupted as a consequence. He invoked his social conscience in the context of his chemical theories, and wrote to Claude Berthollet: "As a friend of the weak, I have endeavoured to give the doctrine of phlogiston a little assistance."

And Lavoisier, who discovered "no new body, no new property, no natural phenomenon previously unknown" (to quote Justus von Liebig), yet had the greatest influence of this trio on our science, he, Lavoisier, died at the hands of the perversion of the revolution that Priestley supported, and for which the latter was hounded out of his native country.

Nothing is gained, nothing created. Yet, also, nothing is simple. Neither the burning of a candle, nor the breathing of a mouse. Even less so the question of who really discovered oxygen, why the French Revolution changed, what if Lavoisier had lived, and Marat had been a better scientist.

SCIENCE AS THEATRE*

By Carl Djerassi

I write science-as-theatre. What is this art form, and why is it important to me, and of value to anyone else?

The majority of scientifically untrained persons are afraid of science. The moment they learn that some scientific facts are about to be sprung on them, they raise a mental shield. It is those people—the ascientific or even antiscientific—that I want to touch. Instead of starting with the aggressive preamble, “let me tell you about my science,” I prefer to start with the more seductive “let me tell you a story” and then incorporate real science and true-to-life scientists into the tale. On the stage, this is “science-in-theatre.”

My personal ambitions reach farther than having the general public understand what research scientists do. To bridge the gap between science and the other cultures, to make science as real to people as any other job a human being might do on an average day, it is also necessary to illustrate how scientists behave. And it is here that a scientist-turned-author can play a particularly important role.

Scientists operate within a tribal culture whose rules, mores and idiosyncrasies are generally not communicated through specific lectures or books, but through a form of intellectual osmosis via a mentor-disciple relationship. As we struggle to support our mentors in their jousts with journals, the constant jockeying with colleagues and competitors over position and priorities, the order of the authors, the choice of the journal, the quest for the grail of academic tenure—even Nobel lust, that most exalted failing of the great—we learn how the game is played by people in white coats, speaking an impenetrable jargon, but people all the same. To me it is important that the public does not look at scientists primarily as nerds, Frankensteins or Strangeloves. And because science-in-fiction or science-in-theatre deals not only with real science but also with real scientists, I feel that a clansman can best describe a scientist’s tribal culture and idiosyncratic behavior. But while science is inherently dramatic, because it deals with the new and unexpected, are scientists dramatic personae—an indispensable criterion for a successful play? Or do our

* This article is an extract of the Dennis Rosen Memorial Lecture at the Royal Institution, London, first presented on June 30, 2000. An expanded version is found in chapter 11 of C. Djerassi, "This Man's Pill," Oxford University Press, Oxford and New York, 2001.

idiosyncratic traits as scientists appear so queer or dull to the rest of the world that we will never appear in successful plays unless represented in the extreme?

Before turning to my own efforts as a scientist turned fiction writer and then playwright, let me demonstrate that theatre with didactic scientific elements is not invariably doomed to failure; that not all audiences (as the *New York Times* critic Bruce Weber recently wrote) are so conditioned by low-brow entertainment that they are only prepared to have their senses tickled, but not their brains massaged. Of course, most non-scientist playwrights use science for metaphorical purposes. I rather doubt that Stoppard's motivation in writing "*Hapgood*" was to illustrate Einstein's photoelectric effect or Heisenberg's Uncertainty Principle, both of which are described at length by a physicist-turned spy, named Kerner. Here is a brief excerpt from one of Kerner's speeches:

> "*The particle world is the dream world of the intelligence officer. An electron can be here or there at the same moment. You can choose; it can go from here to there without going in between; it can pass through two doors at the same time, or from one door to another by a path which is there for all to see until someone looks, and then the act of looking has made it take a different path. Its movements cannot be anticipated because it has no reasons. It defeats surveillance because when you know what it's doing you can't be certain where it is, and when you know where it is you can't be certain what it's doing: Heisenberg's uncertainty principle; and this is not because you're not looking carefully enough, it is because there is no such thing as an electron with a definite position and a definite momentum…"*

Stoppard was writing a fiendishly clever whodunit—not an explication of 20th century physics—and he was neither the first nor the last to use Heisenberg's physics as metaphor, although using Einstein's photoelectric effect (which I will not quote) was more unusual.

In the days before Michael Frayn's *Copenhagen* became a hit, whenever I decried the dearth of "science-in-theatre," three plays were invariably brought up as examples of that genre: Brecht's "*Life of Galileo*, Dürrenmatt's "*The Physicists*," and Tom Stoppard's "*Arcadia*." But Brecht's and Dürrenmatt's motivation was primarily to express their skepticism about science; the actual science played a minimal role. Brecht's politics made him question any science that was not devoted to the service of the people, while Dürrenmatt in expressing his fear of atomic and nuclear annihilation at the height of the Cold War put his Newton, Einstein and Möbius characters into an insane asylum, which became his metaphor for the physicist's world. *Galileo*, of course, illuminates also the conflict between religion and science and the ultimately flawed natures of scientists and of men of the cloth—topics that for me make that play much more timely than *The Physicists*. A new production of Dürrenmatt's play last year in Vienna's Volkstheater seemed to me totally outdated in its message.

That leaves *Arcadia*. I am an enormous fan of Stoppard's plays, so much so that my admiration borders on uncritical idealization. *Arcadia* is a close second to my personal favorite, *Travesties*. But is *Arcadia* "science-in-theatre"? Of course it has didactic sequences—indeed rather long ones. A description of Fermat's last theorem appears within the first few minutes of the play, right after a long and hilarious definition of "carnal embrace." Septimus Hodge, the tutor, has this to say:

> "*Carnal embrace is sexual congress, which is the insertion of the male genital organ into the female genital organ for the purposes of procreation and pleasure. Fermat's last theorem, by contrast, asserts that when x, y and z are whole numbers each raised to power of n, the sum of the first two can never equal the third when n is greater than 2."*

But while Fermat reappears here and there for brief moments, it is iterated algorithms and chaos theory that occupy the better part of a scene in *Arcadia*, with one monologue covering almost an entire page of text. Some of it is quite straightforward:

"You have some x- and y-equation. Any value for x gives you a value for y. So you put a dot where it's right for both x and y. Then you take the next value for x which gives you another value for y, and when you've done that a few times you join up the dots and that's your graph of whatever the equation is…. [But] what she's doing is, every time she works out a value for y, she's using that as her next value for x. And so on. Like a feedback. She's feeding the solution back into the equation, and then solving it again. Iteration, you see."

Later sequences become more complicated as they explain the use of such approaches to contemporary population biology. I suspect that Stoppard's real motivation for many of his didactic forays was not to teach his theatre audience about iterated algorithms. Rather, *Arcadia* had to do with nature and how we humans handle and mishandle, or understand and misunderstand it. Listen to this sequence from the same scene:

> "*People were talking about the end of physics. Relativity and quantum looked as if they were going to clean out the whole problem between them. A theory of everything. But they only explained the very big and the very small. The universe, the elementary particles. The ordinary-sized stuff which is our lives, the things people write poetry about—clouds—daffodils—waterfalls—and what happens in a cup of coffee when the cream goes in—these things are full of mystery, as mysterious to us as the heavens were for the Greeks. We're better at predicting events at the edge of the galaxy or inside the nucleus of an atom than whether it'll rain on auntie's garden party three Sundays from now."*

A few lines later appeared the punch line, "*It's the best possible time to be alive, when almost everything you thought you knew is wrong.*" Somehow, coming from the pen of a non-scientist of Stoppard's renown, it has a more authentic and less self-serving ring than if a professional scientist had written those words. Still, I believe that the science in Stoppard's plays—even the most didactic sequences—are there because Stoppard decided to write a play for which scientific concepts are useful and intellectually attractive metaphors. But they are not intrinsic to the story. *Arcadia* could have been written without Fermat's last theorem or even without chaos theory as a literary lark around Lord Byron. It would not have been the same play, but it still would have been performed and most likely also acclaimed as a successful play.

This is less true in Hugh Whitemore's "*Breaking the Code.*" Fairly early in the first act of that marvelous play, in Scene 5, the mathematician Alan Turing delivers a monologue three pages long, which any instructor in Playwriting 101 would consider grounds for dropping the student from the class. Yet Derek Jacobi, in the role of Alan Turing, did manage to describe David Hilbert's insistence on consistency, completeness, and decidability as basic requirements for mathematics in an elegantly accessible manner as well as Kurt Gödel's subsequent demonstration that no mathematical system could be both consistent and complete. You will have to take my word for it—without my reading three pages of text—that this extremely didactic prose works even for audiences that had never before heard the names of the German Hilbert or the Austrian Gödel—two of the brightest stars in the mathematical firmament. Why did Whitemore put them there? Because the theme of his play was the "Turing machine" and its use in the breaking of the German Enigma code; and to understand that, some of the underlying math was indispensable. Whitemore even used mathematical didacticism for a touching interlude between Turing and his female friend Pat Green by producing a fir cone and then telling her about Fibonacci sequences. And here I quote:

> "*A Fibonacci sequence is a sequence of numbers where each is the sum of the previous two; you start with one and one—then one plus one equals two—one and two, three—two and three, five—three and five, eight—five and eight, thirteen…. Now look at that fir cone. Look at the pattern of the bracts—the leaves. Follow them spiraling round the cone: eight lines twisting round to the left, thirteen twisting to the right. The numbers always come from the Fibonacci sequence…. And it's not just fir cones—the petals of most flowers grow in the same way…. And it prompts the age-old question: is God a mathematician?"*

Of course, it is the very next line that demonstrates that we are dealing with human interactions in a drama and not just a lecture, because Pat then says: "*I love you, Prof. I love you. You know that."*

Now I want to turn to what I will classify as pure "science-in-theatre" plays (written by two first-class playwrights lacking any sort of formal scientific credentials) where the very plot and rationale for the play rests on scientists and their science. Without them, there would be no play. Coincidentally, both first opened at the Cottesloe Theatre of the NRT.

I shall start with Stephen Poliakoff's "*Blinded by the Sun.*" I still remember the evening in September 1996 when I turned to my wife as we walked out of the Cottesloe to announce that I was going to write a play myself—a decision prompted by the mixed feelings that "*Blinded by the Sun*" had engendered in me as a scientist. The play attempted to illuminate some of the idiosyncratic aspects of a scientist's drive for name recognition as well as the competitive aspects of a collegial enterprise through a theatrical version of the chemical "cold fusion" fiasco of the early 1990s. As the first act progressed, I was impressed by how accurately a non-scientist playwright had caught some of the behavioral characteristics of academic scientists and the atmosphere of a red brick university in the UK—so different from the California academic pressure cooker I inhabit. (At that point, I did not know that Poliakoff's brother was a chemistry professor). Even his first foray into explaining the scientific problem under investigation—a Sun Battery— to the scientific ignoramus surrogate needed in all scientific plays seemed effective.

> "*Water contains hydrogen. But how to get it out? Some chemical reactions are caused by shining a light. Find the right chemical to act as a catalyst—shine a light, a beam, above all the sun—and you can create hydrogen out of sunlight and water. Hydrogen, which will run planes, cars, anything you want. And when you burn it, it will turn back into water. Polluting nothing.*"

So far so good. After all, that's why the initial claims by Pons and Fleischmann in 1989 to having discovered cold fusion had caused such a sensation among chemists and physicists and even the general press. But on the following page in the play's text, scientific didacticism raised its ugly head.

> *ELINOR: Is it anatase or rutile? You haven't used an adsorbed dye to shift the Lambda-max, clearly—*
>
> *CHRISTOPHER: The particles have an electrodeposited coating. It's only a few nanometers thick so refractive index matching makes it—*
>
> *ELINOR: Yes, it certainly seems to have a high quantum yield. Maybe there's an added sulfonated surfactant to enhance mass transport at the surface?*
>
> *CHRISTOPHER: No. Think more of a catalytic system—*

To an audience equipped with more curiosity than knowledge about science, such words constitute meaningless gobbledygook. Did Poliakoff have his scientists speak these lines because he felt that a theatre audience would not have understood the real chemistry? Or is the playwright, dealing with serious science, faced by an intrinsic barrier unrelated to the theatre?

Michael Frayn's "*Copenhagen*" suggests that such pessimism is not always justified. Or to put it another way, that it depends on the science one wishes to illuminate. Chemistry may be tougher than physics or astronomy or math because of its heavy dependence on chemical structural formulae. Frayn displayed true courage by refusing to concede to scientific illiteracy. He draws upon quantum mechanics and the uncertainty principle for much of the scintillating interplay between two Nobelists, Werner Heisenberg and Niels Bohr with Margrethe Bohr playing the role of the non-scientists at whose level the didactic passages had to be pitched—a point made openly clear in the following comment of Bohr to Heisenberg:

> "*You know how strongly I believe that we don't do science for ourselves, that we do it so we can explain it to others… in plain language. Not your view I know—you'd be happy to describe what you were up to purely in differential equations if you could—but for Margrethe's sake…"*

Though pleased for what the success of *Copenhagen* has done for "science-in-theatre" and the sudden attention that genre is now receiving (just consider a series of major articles by three different critics in the April 9, 12, and 14 issues of the *New York Times* alone), I am still surprised at its meteoric rise. That the author was an established playwright known for his humor undoubtedly helped. I am absolutely convinced that if the identical script were sent over the transom to London or Manhattan theatres by an unknown playwright, it would not even have been read, let alone produced. Pages of didactic exposition by two characters, where uncertainty in perception and memory rather than dramatic excitement reigns, is not the stuff out which hits are usually generated. I have to admit that I loved the play—and seen it twice—at the Cottesloe and in the West End. But what about the bulk of the audiences—the non-scientists? Do they accept such material in the same spirit of awe that made several million people buy copies of Stephen Hawking's *Brief History of Time* for display on coffee tables? And how would the average literary manager of a theatre respond if he had happened on the following page of a script by an unknown playwright?

Heisenberg: *Max Born and Pascual Jordan in Göttingen.*
Bohr: *Yes, but Schrödinger in Zürich, Fermi in Rome.*
Heisenberg: *Chadwick and Dirac in England.*
Bohr: *Joliot and de Broglie in Paris.*
Heisenberg: *Gamow and Landau in Russia*.
Bohr: *You remember when Goudsmit and Uhlenbeck did spin?*

Heisenberg: *There's this one last variable in the quantum state of the atom that no one can make sense of. The last hurdle—*
Bohr: *Pauli and Stern are waiting on the platform to ask me what I think about spin.*
Heisenberg: *Then the train pulls into Leiden.*
Bohr: *And I'm met at the barrier by Einstein and Ehrenfest*.

I readily admit that it is unfair to quote any passage from a play out of context, but the above may well represent a world record for the number of different surnames—sixteen in all—appearing within a single page of a play. Frayn's presumed justification—which I applaud—was didactic realism rather than the euphony created by this potpourri of European surnames, many of them familiar only to physicists. To my knowledge, *Copenhagen* received uniformly complimentary reviews and commentary with one exception: a serious critique by an American historian, Paul L. Rose, the author of a recent book entitled "*Heisenberg and the Nazi Atomic Bomb Project*." In his lengthy piece in the *Chronicle of Higher Education*—our American equivalent of your THES—Rose compliments Frayn on the theatrical aspects of *Copenhagen*, but chastises him severely on a major didactic point. Not on quantum physics and complimentarity, but on the revisionist nature of Frayn's interpretation of Heisenberg's role in the putative German atomic fission project. This is a serious point, because it was this historic aspect of *Copenhagen* that represented the dramatic focus of the play. I will not further dwell on Rose's criticism other than to mention that for didacticism to work in a play or a piece of fiction, it ought to be accurate. Of course, scientific and historical accuracy are two different things. Frayn anticipated this argument, which is also the reason why the published text of the play contains a densely written authorial postscript defending his interpretation of the historical record.

Having written at length about some of the masters of science-in-theatre, let me end with a novice, Carl Djerassi. In contrast to the professional playwrights I have cited so far, who mostly want to use science for their theatrical aims, I am starting from the opposite side, using the stage for my scientific missionary purpose. The topic I picked for my first play, *An Immaculate Misconception*, is recent, cutting-edge research in reproductive biology.

Here's a nugget of biological information that is unfamiliar to many. A fertile man ejaculates on the order of 100 million sperm during intercourse even though only one single sperm enters the woman's egg during fertilization. A man with 1 – 3 million sperm—seemingly still a huge number—is functionally infertile. And since at least one third of all cases of infertility are due to problems of the male partner, treatment of that condition by means of the ICSI technique (the laboratory insertion of a sperm into an egg) is in my opinion the single most important development in reproductive medicine during the past decade. ICSI was invented in Belgium by Gianpiero Palermo, Hubert Joris, Paul Devroey and

André C. van Steirteghem and only published in Lancet in 1992, yet by now over 10,000 ICSI babies have already been born. The vast majority of the public coming to *An Immaculate Misconception* will never have heard of ICSI, yet I can state unequivocally that after having seen my play everyone will not only know what ICSI is, but will also be able to explain it. And if that claim is true, then this "science-in-theatre" has indeed fulfilled a valuable pedagogic purpose.

The second play of my projected science-in-theatre trilogy, "*Oxygen,"* is what you will see or have read. The main theme of "*Oxygen*" is that behaviorally speaking, little has changed over the course of two centuries in the motivation and conduct of scientists in their drive for recognition and priority. Elsewhere in this Study Guide you will find a synopsis of the play, a list of characters, and some questions for discussion. We think you will enjoy the play.

In the March 16, 2000 issue of *Nature,* Allison Abbott reported on the current project at CERN, the European Laboratory for Particle Physics, whereby distinguished artists are brought to Geneva to "*learn about high-energy physics and [to] respond by creating an original piece of art during this year."* One of the artist participants, the Turner Prizewinner Richard Deacon, was quoted as saying, "*We need to listen to each other, but not necessarily to understand. The misunderstanding in both directions can be creative."*

Creative it may well be, but is misunderstanding productive in terms of narrowing the gulf between scientists and artists or does it simply accentuate that gulf? I am a firm believer in the ultimate virtue of understanding—and if "science-in-theatre" contributes to that aim, I will regard my current dedication to playwriting as very well spent.

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ETHICAL ISSUES IN CHEMICAL RESEARCH

Roald Hoffmann

(Lecture, New Orleans Meeting of the American Chemical Society, 3/26/96)

I am not qualified, in any way, to speak on ethics, neither by reason of great personal righteousness, nor by deep study of ethics, nor by extensive professional confrontation with ethical problems that affect our science. Worse, I do have a tendency to get preachy, I know, which is hardly the best approach to getting people to face ethical problems.

I am reconciled, just a little, to talking to you about this subject, by my acquaintance with good psychologists and priests, from whom I have learned that you don't necessarily need to enter personal hells to help people emerge from them. I also begin with a deep respect for the sources of our ethical tradition, in particular for religion (even as I am unreligious), for philosophy, and for the law. Also I think of myself as a watcher, an observer. Not disinterested, but sympathetic to the complexity of human experience. Also I've been trained to say "yes". So, asked to speak on ethics by my friend Eli Pearce, I try.

Let me begin with several suppositions, some of which will certainly get me into trouble with some people.

1

Modern science is an incredibly successful Western European social invention, an efficient enterprise for gaining reliable knowledge of some aspects of this world, and for using that knowledge to transform the world. At its heart is careful observation, of nature and of our interventions in it. Implicit is that such observation be carefully reported, in an open literature available to all. And that the observations be as reproducible as they can be. There is most certainly a role for imaginative thinking (some call that theory, some fantasy) in the enterprise. However, what distinguishes modern science from other ways of knowing this world is its unremitting built-in dipping back into reality from the wonderful fancies of the mind. Theories and equations are continually tested; if you don't test them, someone else will.

2

Who does science, and why? Science is done by human beings and their tools. Which means that it is done by fallible human beings. The driving forces for acquiring knowledge include, to be sure, curiosity, aesthetics, and altruism. But creating is just as surely rooted in the irrational, in the dark, murky waters of the psyche where fears, power, sex, and childhood traumas swim in all their hidden, mysterious movements. And spur us on. Not only do character and deep-down motivations matter — their seemingly "unsavory" side may well be the driving force of the creative act.

In this context I would like to quote to you an ancient (roughly two thousand year old) Jewish midrash, a story taken out of a set of commentaries on the Bible. It concerns the yetzer hara, literally evil inclination, but standing for the devil or satan: Once God banished the yetzer hara from the world. There was no more jealousy, no more pride, no ambition, no libido. What was the result? In the year that followed no houses were built, no children were born. Eventually, mankind begged God to return the yetzer hara to this world.

The sources of imagination, creativity, and diligence aside, scientists are no better than anyone else, just because they're scientists. The reason I say this so plainly and so strongly is that there is a real danger of self-serving delusion here, fired by the fact that from childhood we've been taught that being smart (in the way scientists are smart) is being good. Good at school, yes. But life is not school, and the feelings of people are not reagents. Scientists are not born with ethics. Nor, for that matter, are they born with aesthetics and logic.

Exaggerated claims to rationality are not supported by the personal conduct of scientists. There is a tremendous range of behavior that accompanies success in acquiring reliable knowledge — every scientist will tell you what a bastard well-known and talented colleague X,Y, or Z is. And if there is any evidence of more rational or compassionate behavior on the part of scientists toward their spouses, children and parents, compared to other people, I haven't seen it. To put it another way -- if scientists are more rational than other people (as they would sometimes like others to think), boy, have they done a great job of limiting their rationality to their working hours.

You might think from this that I'm down on chemists and what they can do. Not at all; I think those of you who've read what I've written, of the work of others, will know that I love all we have done, be it the making of a complex cubical molecule shaped out of DNA, the elucidation of how NO spins off a surface. What we have achieved is so incredibly beautiful -- what I hate to have the beauty of creating and discovery, of human beings doing more than they thought they were capable of doing, reduced to mythological drivel in which saints do the saintly.

Let me call up a cultural referent, which is now, I think, well known to everyone — Peter Shaffer's play, *Amadeus* — either from a theatrical production or its film version. The theme derives from a poem by Pushkin, "Mozart and Salieri." You remember the story: Salieri cannot understand. At one point he say, in effect, “How could God have put such heavenly music into such a crass vessel?” We would like to think that Mozart was angelic, but in fact the great composer had a complicated personal and public life.

Let me tie together these two points, of a great proven social system for acquiring knowledge based on the creative impulses of normal, fallible human beings, by saying a few words about fraud in science. Fraud in science is not a real problem. This is because of the psychology of the perpetrators of fraud, and the self-checking nature of the system. The psychopathology of fraud is such that its perpetrators hardly ever contain themselves to manufacturing routine data. Instead they doctor something important. And there are extraordinarily efficient self-correcting features in the system of science — the more interesting the discovery or creation, the more likely it is to be repeated and tested (often not because people want to prove someone right, but just the opposite, to prove them wrong).

So why the extraordinary public interest in the few cases of fraud in science? I suggest that it comes from the same sources that make us intensely interested in the occasional sexual misdeeds of our clergy. We know they are human beings, but they are priests. And if we set scientists, ourselves, up as priests of truth rather than seekers after reliable knowledge, we have just that much further to fall in the eyes of those whom we’ve fooled into believing that we are priests.

3

My third supposition is that we live in a state, by mutual consent. At times we forget the social contract which we have entered through birth; hardly anyone reminds us of it. And some have opted out of it. Still I find it remarkable how natural adherence to that social contract is, among such variety in human beings.

Here is how Thomas Hobbes describes it, in 1651 in “Leviathan” or “The Matter, Forme, and Power of a Common-Wealth, Ecclesiastical and Civill”.

> *NATURE (the Art whereby God hath made and governes the World) is by the Art of man, as in many other things, so in this also imitated, that it can make an Artificial Animal. For seeing life is but a motion of Limbs, the begining whereof is in some principal part within; why may we not say, that all Automata (Engines that move themselves by springs and wheeles as doth a watch) have an artificiall life? For what is the Heart, but a Spring; and the Nerves, but so many Strings; and the joynts, but so many Wheeles, giving motion to the whole Body, such as was intended by the Artificer? Art goes yet further, imitating that Rationall and most excellent worke of Nature, Man. For by Art is created that great LEVIATHAN called a COMMON-WEALTH, or STATE, (in latine CIVITAS) which is but an Artificiall Man; though of greater stature and strength than the Naturall, for whose Protection and defence it was intended; and in which the*

Soveraignty is an Artificiall Soul, as giving life and motion to the whole body; The Magistrates, and other Officers of Judicature and Execution, artificiall joynts; Reward and Punishment ...are the Nerves, that do the same in the Body Naturall; The Wealth and Riches of all the particular members, are the Strength; Salus Populi (the peoples safety) its Businesse; Counsellors, by whom all things needfull for it to know, are suggested unto it, are the Memory; Equity and Lawes, an artificiall Reason and Will; Concord, Health; Sedition, Sicknesse; and Civill war, Death.

Without human beings yielding some of their individual right to the state, civilized life would be impossible.

Three hundred and fifty years later, 2500 years after the invention of Athenian democracy, we're still trying to sort out the right balance of individual and state rights.

But there is no doubt that scientists have signed that social contract. And that superlative knowledge of the workings of nature is not an excuse to transgress civil or criminal statutes. Worse, just the presumption that possessing such knowledge makes one superior, in some way beyond the law, is at the least false pride, a puffing up. It is an opting out of the social contract, by people who should know better. I told you I was preachy. But it is Sunday morning.

4

One final supposition, a tiny one, is that there is a difference between normative principles and real life. And a role for both. I should come to a full stop at a stop sign or blinking red light, I know it. But in reality I 'sort of' do it; if I really took videos, bothered to define a stop as a velocity of <0.001 m/sec held for >0.1 sec., then I'd be judged as coming to a full stop about one third of the time. OK, so I'm bad.

If a polity violates more seriously laws as a matter of fact (e.g. some states have sodomy laws between consenting adults) then a case could be made that such laws on the books erode public confidence in the legal system. Our laws are a curious mixture of our aspirations, of moral consensus expressed, however badly, by our representatives, and reality. Laws are perforce normative, and not expressions of average social behavior. This is fine, I think, it is as it should be. For we live by aspirations, as well as by existential acts.

5

With some of my principles voiced, let me approach some seemingly disparate ethical problems in our profession, each via a question.

A. Are there any bad molecules? Actually, the matter I want to deal with, sloganized by this question, is whether it is proper for a government to prohibit research, synthesis, or sale of a molecule. Or are there constraints on scientific research?

The first answer is “no, there aren’t any bad molecules.” Only bad people. The point is more interestingly made in the context of molecules that both heal and harm, of ozone and morphine. Ozone is a harmful pollutant at sea level, a saving filterer of UV radiation in the stratosphere. Morphine is our most wonderful painkiller, and very addictive.

The “no bad molecules, only bad people” slogan, of course, evokes the argument of the anti-gun-control lobby. Is it right to ban guns, or to ban molecules? My opinion is that society has the right to ban both. It should exercise that right with care...

Let me be specific, and speak about thalidomide. You know that terrible story of the unscrupulous marketing of a potent teratogenic agent (I describe it in my book “The Same and Not the Same”). In the sequel the world spoke clearly “never again,” and put into place laws and regulatory regulations to ensure that.

And now the FDA has approved the manufacture of thalidomide in the US. It is active against hanseniasis (leprosy) and there are indications that thalidomide inhibits HIV. Should one license prescription of the drug, with all the warnings in the world against its use by pregnant women?

Here is my personal opinion, with which some will surely disagree. I think the molecule should be banned. Why?

Well, another country (Brazil) has tried the experiment of limited licensed use against leprosy, while taking measures to warn and monitor patients against use by pregnant women in the first trimester. Nevertheless, the drug has been misused, in a variety of circumstances, and there are apparently several dozen documented recent thalidomide-deformed births (See Estado de S. Paulo, May 20, 1994, and a Brazilian thalidomide victims association, A.B.P.S.T.).

Perhaps the medical system in the US is better than in Brazil, so misuse could not occur here, for instance if the drug were licensed for AIDS-related syndromes. I’m not that sure. My opinion is that there are some effects of a pharmaceutical that have moral consequences of a nature such that the normal and agonizing risk equation (benefit to some, vs. potential harm to others) just cannot be used. This drug should not be licensed, in my opinion, under any circumstances.

Instead, pharmaceutical researchers should be given incentives to develop thalidomide-related molecules which are effective but do not cause birth malformations.

You need not agree with me. But I think there are very few extreme libertarians who would argue that governments do not have the authority to constrain the making, sale, or consumption of one or another molecule. Think of angel dust. Think of hydrogen cyanide. There are no evil molecules, but governments can forbid people to make certain molecules.

6

My first issue was one of potential conflict between the interests of chemists and those of society. Most of us in creative research do not encounter such areas of overt conflict. Yet we do face up to a variety of ethical issues internal to our microsociety, issues which are not of legal import. I want to touch on some of these, and do so through three further questions:

B. <u>Is it admissible to delay the review of a competitor's paper in one journal so as to rush into print in another journal your own synthesis of a compound you've been working on for years?</u>

C. <u>Can you publish a structure of a molecule and not make its coordinates available to others?</u>

D. <u>Should you join the editorial board of a journal that charges a subscription price of $10 per page published?</u>

Here are my answers:

B. Of course not. This is highly unethical.

C. You can publish such structures, but you shouldn't, I think. You can, because, in part, the competition of the "prestige" science journals, especially in the biomedical area -- Nature, Science, Cell -- to publish the hottest papers, drives the journals to look the other way when their own guidelines in this matter are violated.

Yes, people don't want to give away that precious, hardwon, structural information. Especially when the goal is to design an inhibitor of that enzyme, and out there is a multimillion dollar pharmaceutical market, and out there are also people with much better modeling programs than you have, just waiting to design that molecule docking at the active site of the enzyme.

And yes, people are also lazy, once the main part of the story falls into place, too lazy to clean up and prepare the data in the shape required by the crystallographic data bases. And maybe one is ashamed of the data.

The tension of wanting a field to oneself contends in all scientists with the imperative to publish. It always has. And none, absolutely none, will today listen to a 19th century final sentence in the paper "I reserve the field for myself." For that matter, none listened in the 19th century except when the reserver was a person of power...

It's just fine to opt out of the system, and not publish. But the community should be insistent, I think, that what is published should be in principle reproducible. So coordinates must be published expeditiously; there are ways to ensure that this is so. I am glad that the Guidelines of the ACS Committee on Publications emphasize this, and give much useful and well-thought out ethical guidance on other publication matters.

D. No you shouldn't join the board of that journal. That is my opinion, made with hesitation about the intrusion into your freedom, but made with conviction. Let me explain.

Even the greatest library I know, Cornell's, has begun to cancel journal subscriptions. Our libraries no longer subscribe to every journal published, as they used to.

So if journal proliferation is a problem, it seems that it is about to be controlled in the best way, by market forces. Nevertheless, profit-hungry publishers continue to charge our libraries exorbitant prices for subscriptions. And the publishers find enough scientists dissatisfied with what there is, or desirous of the recognition that journal editorship entails, to stock, with ease their editorial boards.

I phrased my question in the personally most provocative way -- attacking a problem that we all recognize, but doing so by addressing not the economics of libraries but the free choice of human beings, my colleagues, to do or not do something. You can bet your Mardi Gras necklace that your friends will not like you telling them what they should do. I know, I once tried...

These last three questions progress from one (B) everyone could agree on, to another one (D) on which reasonable men and women might differ. But I want to point to the common subject of all three ethical considerations: they refer to actions that are certainly not illegal, but which (to a varying degree) violate the ability of science to function. They are crimes against our micro-leviathan. Let me tell you how.

In the case of (B): Deliberate delaying of a competitor's paper in the refereeing process is an action that carries the potential of destroying the whole system. The confidence of all is shaken by such a flagrant violation of the open communication process on which science depends.

In the case of (C): The refusal to publish data which forms the basis of a conclusion strikes at the heart of the scientific communication process. Discoveries stand on the shoulders of giants (that's all those citations). And add to the structure from which others (and the authors) can reach for greater understanding.

In the Case of (D): Exorbitantly priced journals are simply not available in underdeveloped countries. That vaunted, wonderful window on the new that is given to us here in every issue of a journal, that window which makes science possible, simply does not open in Dar-es-Salaam, Managua, or Baku. This is simply unethical, even if it is distanced from us by a subscription price. What good is it to talk of freedom, to publish and do good science, when you can't get access to a single copy of that journal in your country?

I realize that asking people not to join editorial boards is an offensive infringement of personal rights. So let me suggest a compromise: Next time someone asks you to join the editorial board of a journal published commercially, gently ask them to donate in exchange for your services 50 subscriptions to libraries in developing countries.

I remain of the opinion that we must be especially vigilant of practices that are not simply ethical violations, but which affect the capability of chemistry to function.

7

In the scale of descent of ethical concerns, from greater to smaller, we come to what I view as the least of our worries as a community, and yet (I hazard to guess) the greatest cause of emotional distress to individuals. This is the persistent exaggeration of value of one's own work, i.e hype. And the omission of due credit to others.

Let me be specific: What do you think of a paper by scientist X which bears the title "The first self-assembly of nanoscopic aggregates of..."? As if hemoglobin were not of nanometer dimensions, and good old-fashioned synthesis were not self-assembly! And as if scientist Y, mentioned in the references, but lumped together with a bunch of other unimportant contributors, had not made a related molecule!

What is the effect of publications like this, aside from the pain to scientist Y? The incredible thing is that scientist X cannot see, just cannot see, that by attaching himself to fashionable buzzwords such as nanoscopic, self-assembly, etc. he or she is <u>subtracting</u> value (in the eyes of careful readers, good scientists, experts in the field) from his work, rather than adding to it.

So...yes, omission of related or preceding work causes pain. But hype, <u>so</u> easily recognized, doesn't really hurt the community. It actually works against its spinners. So I'm not worried about this.

8

I would like to conclude with a return to the broader picture, to the interactions of chemists with society. Here is what I see as our social responsibility to our fellow human beings.

Molecules are molecules. Chemists and engineers make new ones, transform old ones. Still others in the economic chain sell them, and we all want them and use them. Each of us has a role in the use and misuse of chemicals.

We are sentenced by our nature to create. There is no way to avoid investigation of what is in or around us. There is no way to close one's eyes to creation or discovery. You can (and in certain circumstances, you should) make a decision to work on a certain molecule. But given the realities of the world, if you don't find that molecule, someone else will. At the same time I believe that scientists have absolute responsibility for thinking about the uses of their creation, even the abuses by others. And they must do everything possible to bring those dangers and abuses before the public. If not I then who? At the risk of losing their livelihood, at the risk of humiliation, they must live with the consequences of their actions. It is this which makes them actors in a classical tragedy and not comic heroes on a pedestal. It is this responsibility to humanity which makes them human.

Each of us must face the ethical problems of our lives in the light of our own traditions. The only advice I would presume to give is “mind the shade”.

Let me explain. Very little in this world is pure good or pure evil. Yet evil gets done, and no, it is not the work of Satan, it is the accumulated work of men and women. If there be people who mean ill, they long ago learned that responsibility for exploitation or hurt had best be diffused. So that an individual in the chain be tempted as little as possible to question the immensity of the overall evil action.

Or maybe people intent on no good construct psychological diversions and camouflages for themselves. So even they do not see harm to others, only easily rationalized profit to themselves.

Given this psychological tendency (of evil to diffuse itself), actions which are ethically gray or shaded, neither inherently good nor bad, should be thought through by people in great depth. If there be two data points in a test set which indicate disagreement with a theory, or side effects of a drug, shall I discard them before I tell my supervisor? It seems so easy, so harmless, to do so. But the cumulative effects of such selective shading may be disastrous. As difficult as it is to think about these small things, perhaps we should be grateful that as human beings we are presented with choices that only human beings can make.

Acknowledgment: I am grateful to my research group for helping me construct this lecture, and to Shira Leibowitz and Rivka Schechter for leading me to some highly relevant quotations.

QUESTIONS FOR THOUGHT, DISCUSSION AND WRITING

1. After viewing or reading “Oxygen,” to whom would you award the Retro-Nobel? Why?

2. How do theatre artists collaborate to create a production? How do scientists collaborate to discover new things? What are the major similarities and differences between the creative process in science and art? Is there art in science? Is there science in art?

3. Here is a statement for you to agree or disagree with: “Very often a discovery is not simple, and many people are involved, to a varying degree. Any reward, such as the Nobel Prize for that discovery, should go to absolutely every person involved in that discovery, as long as they contributed to a significant extent.” Why do you agree or disagree with this statement?

4. If someone discovers something, but doesn’t publish the results, what should people do when it comes to rewarding that discovery if someone else makes the discovery sometime later but publishes it?

5. If two people discover something independently, what should the person who makes the discovery later do upon learning of the first discovery? (assuming he or she didn’t know of it in the first place). What should the first discoverer do when he or she hears of the second discovery?

6. Is there any difference in the answers one might give to the above questions if the discovery (a) has no commercial value, and (b) can be used to make a product of great commercial value?

7. How does this piece relate to school subjects besides art and science? (i.e.—history, social sciences, math, literature)

8. Why is chemistry important? Make a list with your class of some of the ways that chemistry affects our lives, or major industries.

9. Learn more about one of the historical characters in the play, using the library or on the Internet (see the following page for web sites). When you have gathered information about the person, create a work of art based on your research. The possibilities are endless. Here are some suggestions to get you started:

   Write a poem about Fru Pohl and Carl Wilhelm Scheele
   Paint a portrait of Lavoisier’s wife (she was a painter herself)
   Write a song or rap about Priestley as a religious dissenter

Write a monologue about how Lavoisier must have felt as he was led to the guillotine in 1794.

10. What is the actual reward that Nobel Prize winners receive? Why do the media pay so much attention to it?

11. What are the different ways in which scientists are rewarded in this world for the discoveries they make?

12. To what extent does the Nobel Prize differ from the Oscars or top athletic awards?

13. Write a short review that discusses what you thought about specific aspects of the play. Topics might include scenery, lighting, music, acting, costumes or themes. Do NOT write about the plot—"what happened"—everyone saw or has read the play. Write about your own thoughts and opinions.

ADDITIONAL READING ON ETHICS IN SCIENCE

First, two useful **web sites**:

Linda Sweeting: http://www.towson.edu/~sweeting/ethics/ethicbib.htm. This is a fantastic web site, including hundreds of annotated sources.

The Ethics Center for Engineering and Science at Case Western Reserve (CWRU), http://ethics.cwru.edu.

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BIOGRAPHIES OF AUTHORS

Carl Djerassi

Carl Djerassi, born in Vienna but educated in the US, is a writer and professor of chemistry at Stanford University. Author of over 1200 scientific publications and seven monographs, he is one of the few American scientists to have been awarded both the National Medal of Science (in 1973, for the first synthesis of a steroid oral contraceptive--"the Pill") and the National Medal of Technology (in 1991, for promoting new approaches to insect control). A member of the US National Academy of Sciences and the American Academy of Arts and Sciences as well as many foreign academies, Djerassi has received 18 honorary doctorates together with numerous other honors, such as the first Wolf Prize in Chemistry, the first Award for the Industrial Application of Science from the National Academy of Sciences, and the American Chemical Society's highest award, the Priestley Medal.

For the past decade, he has turned to fiction writing, mostly in the genre of "science-in-fiction," whereby he illustrates, in the guise of realistic fiction, the human side of scientists and the personal conflicts faced by scientists in their quest for scientific knowledge, personal recognition, and financial rewards. In addition to novels (*Cantor's Dilemma; The Bourbaki Gambit; Marx, deceased; Menachem's Seed*; *NO)*, short stories (*The Futurist and Other Stories*), and autobiography (*The Pill, Pygmy Chimps, and Degas' Horse*), he has recently embarked on a trilogy of plays which he describes in his web site as "science-in-theatre"—with an emphasis on contemporary cutting-edge research in the biomedical sciences. "*AN IMMACULATE MISCONCEPTION,*" first performed in abbreviated form at the 1998 Edinburgh Fringe Festival and subsequently (1999) as a full, 2-act play in London (New End Theatre), San Francisco (Eureka Theatre), Vienna (under the title UNBEFLECKT at the Jugendstiltheater) and in 2001 in Manhattan (Primary Stages), focuses on the ethical issues inherent in recent spectacular advances in the treatment of male infertility through single sperm injection (the ICSI technique). A radio adaptation was broadcast over the BBC World Service as "Play of the Week." He is also the founder of the Djerassi Resident Artists Program near Woodside, California, which provides residencies and studio space for artists in the visual arts, literature, choreography and performing arts, and music. Over 1000 artists have passed through that program since its inception in 1982.

(*There is a Web site about Carl Djerassi's writing at* **http://www.djerassi.com**)

Roald Hoffmann

Roald Hoffmann, born in Zloczow, Poland but educated in the US, is the Frank H. T. Rhodes Professor of Humane Letters at Cornell University. One of America’s most distinguished chemists, he was awarded the Nobel Prize in Chemistry. A member of the US National Academy of Sciences and the American Academy of Arts and Sciences as well as many foreign academies, Hoffmann has received 26 honorary doctorates together with numerous other honors such as the National Medal of Science. Hoffmann is the only person ever to receive the American Chemical Society’s top awards in three subdisciplines: organic chemistry, inorganic chemistry, and chemical education.

For the past dozen years, Hoffmann has simultaneously pursued a literary career. He is the author of three books of poetry, "The Metamict State" (1987), "Gaps and Verges" (1990), and “Memory Effects” (1999). His three non-fiction books deal with the overall theme of the creative and humanistic sparks of chemistry: An art/science/literature collaboration with artist Vivian Torrence, "Chemistry Imagined" (1993); "The Same and Not the Same" (1995); and “Old Wine, New Flasks: Reflections on Science and Jewish Tradition,” in collaboration with Shira Leibowitz Schmidt. Hoffmann is also is the presenter of a television course, "The World of Chemistry", which has aired on many PBS stations and abroad.

