ReAction!

Chemistry in the Movies

Mark Griep & Marjorie Mikasen

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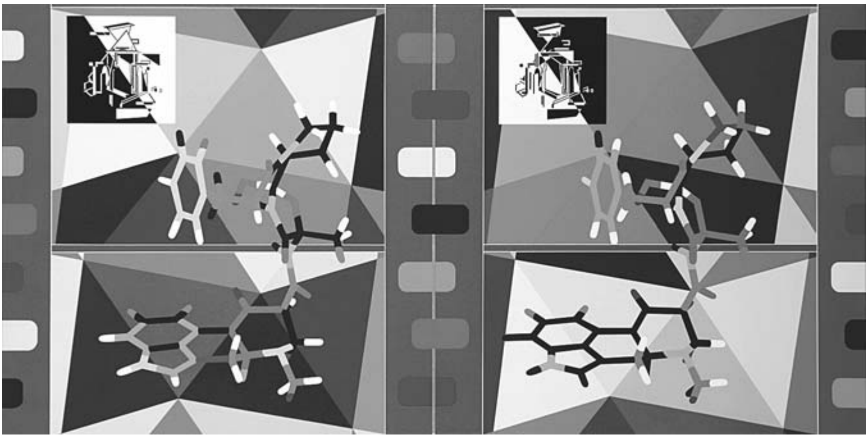

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For our parents

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We have enjoyed watching movies for as long as we remember. We thank the following people and events for inspiring us to enjoy movies and to think more deeply about their meaning. In 1979, M.M. took a course from Tom Conley titled "Italian Neo-Realist Cinema" at the University of Minnesota. M.G. snuck in to watch two of the films. In 1987, we attended Joshua Hassel's "Pop into Film" presentation in Denver. It was sponsored by the Metropolitan Denver Arts Alliance in conjunction with a juried art exhibition titled "Communications '86." Hassel used short clips from 1960s popular and art films to demonstrate the many uses of art in film. From him, we learned of Sixth Avenue Video, run by Sonja, who rented a great collection of movies on video. In 1998, M.G. first read about the National Institutes of Health's "Screening Science" series and wondered how to bring something like that to the Chemistry Department at the University of Nebraska–Lincoln. In 2000, we discovered that Elvis was a chemist in *Clambake*. In 2001, John Fortman presented a wonderful talk in Hastings, Nebraska, titled “Serious and Delirious Uses of Chemistry in the Movies” that was sponsored by the Nebraska Local Section of the American Chemical Society. He paired movie clips with a chemical magic show. In 2007, independent filmmaker Jon Jost included us in his film-in-progress *Swimming in Nebraska*, when he was shooting in Lincoln. We immersed ourselves in the vision of this singular director and learned a bit about making movies at the same time.

The quote (page 81) “It seems to me . . . answers could save us,” is from page 42 of PRISONS WE CHOOSE TO LIVE INSIDE by DORIS LESSING. Copyright © 1988 by Doris Lessing. Reprinted by permission of HarperCollins Publishers. Additional territory: Jonathan Clowes, Ltd., Iron Bridge House, Bridge Approach, London NW1 8BD, England.

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Introduction

The Dark and Bright Sides of Chemistry in the Movies

Almost a decade ago we sat down to watch some pure home video entertainment: *Clambake*, starring Elvis Presley. Halfway through the movie, to our complete surprise, Elvis turned into a chemist! You might say this book began at that moment. In the following pages, we examine the presence of chemistry in one of the most accessible of all cultural products: movies.

It has been noted repeatedly in recent years that chemistry is one of the least popularized areas of the hard sciences. When the term "science" is used in popular culture and the media, it often refers to medicine, physics, and biology. Monsters and superheroes, mad scientists and geniuses, aliens and mutants—all spring with ease from these realms. The discipline of chemistry seems by comparison to be underrepresented in cultural depictions, with an appearance harder to trace and an impact less openly acknowledged. Is this perception truly accurate? One need only name names—Dr. Jekyll and Mr. Hyde—to see that this can hardly be the case. From the silent era through today, it is clear that chemistry has always been in the movies. In fact, chemical themes and characters have been capturing the imaginations of audiences for more than a century. They appear in surprising and significant ways and have generated some of the most enduring fictions and motifs in movie history, and thus in the culture at large. In its starring role, chemistry, the transformative science, has been moving us as it changes with the times.

More than 1,200 motion pictures were compiled, analyzed, and categorized for this project. The sheer quantity of movies containing some aspect of chemistry was eye-opening. What started out as an exercise in curiosity, casually noting the appearance of chemistry themes through random movie viewing, quickly turned into serious study as the numbers kept rising. Inspired by the National Institutes of Health (NIH) "Science in Cinema" film series, we started making a list. Every summer since 1998 (Zurer 1998), the NIH has screened six films, each dealing with a different medical theme, followed by a short scientific analysis from an NIH researcher working in a relevant field. As our own list grew larger, patterns were noted, a web of associations emerged, and trends became apparent.

The two-part structure of this book is driven by what the movies say about themselves. It is clear from the examples on our list that chemistry is portrayed nearly equally as positive or negative in movie story lines. The visual image of a monad comes to mind, a circle with two equal, intertwined parts. The halves of this whole are entangled and interdependent. Each half has its identity amplified and clarified by its relationship with the other. It stands to reason that bad actions and outcomes would not seem so bad if not contrasted with good actions and outcomes, and vice versa. Thus, this book has two parts: the dark side and bright side of chemistry in the movies. Our book can also be seen to embody the duplex chemical character that is Dr. Jekyll and Mr. Hyde and has taken its template from him.

Recently, an advocate for the discipline of chemistry called for more positive, accurate images of chemistry, decrying the misrepresentation of science shown in the Jekyll and Hyde story (Emsley 2006). While one may sympathize with this sentiment, and it may be persuasive on a public relations level, to adopt this viewpoint would gloss over the difficult aspects of human nature. Would it not impose a constrained view on a scientific discipline founded on the principles of free inquiry? In truth, the negative and positive aspects of human needs and desires have always played off of one another, and we ignore this at our peril. There is also a long history of acknowledgment and educational focus in the sciences that connects ethical action to individual responsibility, much of which has evolved from grappling with the enormously destructive impacts of such scientific discoveries as the use of poison gas in WWI or the detonation of the atomic bomb in WWII. Warfare aside, science has made many benevolent but also many insidious inroads into our daily lives, causing us to wonder if our very sense of what it means to be human is at stake. Indeed, as noted in the 1995 National Academy of Sciences publication *On Being a Scientist*, "Science and technology have become such integral parts of society that scientists can no longer isolate themselves from societal concerns." Nevertheless, scientists do not have concentrated training in the areas of ethics and morals. What scientists do well is derive information from the scientific process that can influence the moral values of individuals in society in the areas of religion, politics, and economics. The findings of science are ethically neutral, but the activity of science is not (Bronowski 1965).

Chemistry is the only science that shares its name with an industry, and as such, it carries the heavy associative burden of some negative uses of its discoveries. Since their beginning, motion pictures have mined the human condition for dramatic and comedic material. Anything human beings are capable of, including chemical capabilities, becomes fair game for storytelling. The somewhat innocuous subject matter of movies might seem an unlikely place to explore the complexity of moral issues and personal responsibility related to the science of chemistry. Taken as a whole, however, the movies described in this book show a wide range of possibilities of action and agency in the moral dimension. They give us examples of inner resources or abilities that are developed or neglected by the chemist-actors as they maneuver in situations that present them with competing loyalties. The dialectical arrangement of themes in the dark and bright sides also emphasizes that these themes stand in a relational way to each other and can illuminate each other. Indeed, this may lead to new insights and awareness on the part of the reader. We are not, however, endorsing a relativist position. In fact, we have deliberately reversed the expected coupling of bright and dark—we have intentionally given the bright side the last word. Chemistry is powerful: It has the power to damage, possibly beyond habitation, the planet that is our home. It can take life indiscriminately and ruin health and property. Could one ask for a more potent force? Its responsible use is necessary for our survival. We will need all of our value systems working together to create a better why, how, when, and where for the use of chemistry and its products in the future.

Early in this project we asked friends and acquaintances to name some movies they had seen containing chemistry or references to chemistry, and most commonly they would say *Frankenstein*. The science featured in the 1931 Universal Studios movie production of *Frankenstein* is biology and physics. We wondered why it is so hard to for people to see the chemistry in a movie, why it is so easily overlooked. Maybe it is because chemistry is a practical science, or because chemistry uses symbolic language to convey specialized knowledge, and many people do not have this educational background. Yet the practice of chemistry has its basis firmly in reality.

Since chemistry is sometimes misidentified with other disciplines such as physics, we also wondered why chemistry is, by implication, so frequently associated with the horror genre. The answer may be that it is science and one must keep in mind that the physics of *Frankenstein* and the chemistry of *Dr. Jekyll and Mr. Hyde* both reflect the "terror and promise of science" (Tudor 1989). The two-part character of Jekyll and Hyde is foreshadowed by dualities evident in the Dr. Frankenstein character, namely, his divorce of rational self from emotional self. The character of Dr. Jekyll is more psychologically developed, however, and he owes his separation of personality and compartmentalization of action to his chemical expertise. What both movies also share is that they are based on works of literature.

The 1886 novella *Strange Case of Dr. Jekyll and Mr. Hyde* by Robert Louis Stevenson is the story of a physician/chemist bent on separating the good and bad aspects of human nature. There are many movie versions of this story, down to the present day. One of the most acclaimed is the 1931 version of *Dr. Jekyll and Mr. Hyde* featuring Fredric March, and it solidifies chemistry's central role in cinema history.

But the scope of this book goes beyond cinema history. We feel the Jekyll and Hyde duality of dark and bright holds a key to understanding how chemistry is perceived in Western culture. We are using this duality to guide the structure and presentation of themes in our book. The first five chapters have dark chemical themes, whereas the last five chapters have bright chemical themes. Each chapter begins with a chemical analysis of that theme and ends with chemical and narrative summaries of the movies contained within that chapter.

The chemical analysis of each theme has five sections. The first introduces the theme shared by the movies and chemistry. The second expands on the chemistry behind the source material, usually a book or personal biography, which spawned the majority of movie narratives in that theme. The third section deals with the real chemistry behind the movie narratives. Viewers may well ask: Can the chemistry in the movie really work? The fourth section discusses the psychological responses to the theme, broadening the context and positioning it within a continuum that includes societal, historical, and political dimensions. The fifth section describes the archetypal movie for that theme.

The archetypal movies are selected from a group of about 12 movies that are summarized in each chapter. An "archetype," a term that became widely disseminated through the writings of psychologist C. G. Jung, is the "possibility of representation" (Jung 1980). Traditionally depicted through mythology, religion, storytelling, and art, archetypes find their primary contemporary expression through the mass medium of movies (Indick 2004). The contents that make up archetypes are motifs with typical images and associations, or archetypal ideas, and they have the power to influence and fascinate (Jung 1980). Certain movies are distinguished from others; they very clearly represent the core value and significance of the chemical theme, often exuding a vivid emotional tone. Using chemical imagery in his writings to describe how the framework of an archetype functions, Jung compares its form to the "axial system of a crystal" and notes that the ions and molecules aggregate in a "specific way" (Jung 1970). He suggests that there is something a priori, or a "pre-form," that exists before the crystal has its own material existence. Each of our chapters can be thought of as the matrix on which a striking movie example crystallizes in an archetypal way.

The movies in each chapter were selected by ranking them according to the following criteria: contemporary (meaning released after 1970), available on VHS or DVD, included women or other underrepresented groups in significant roles, or especially favored by one or both of the authors. The idea of an archetype film came out of this ranking exercise after we discovered concurrence between the especially favored categories and some older films.

Even though featuring women protagonists was one of our selection criteria, there are only about a dozen movies in this book featuring women chemists as characters, and another dozen featuring women nonchemists in dominant lead roles. It is not surprising to any contemporary film

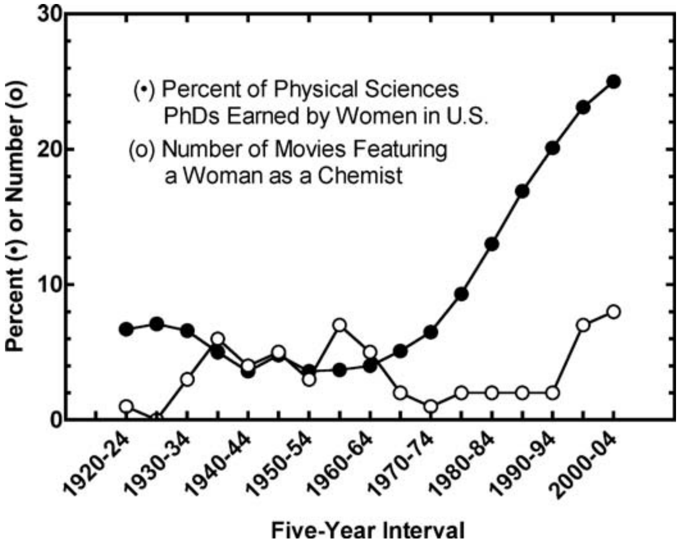

Figure 1. The percentage of physical science Ph.D.s awarded to women (solid circles) and the number of women appearing as chemists in the movies (open circles). The Ph.D. data are from "Doctorates in the 20th Century" (National Science Foundation 2006).

viewer that most movies are about men. It may be surprising to learn, however, that there were more women chemists on the screen in the 1930s through 1950s than there have been since (figure 0.1, open circles). This recent paucity contrasts very poorly with the documented rise in the percentage of physical science Ph.D.s earned by women in U.S. universities (figure 1, solid circles). Chemists earn about two-thirds of the physical sciences degrees.

After the movies were selected for each chapter, we sought to describe the fundamental dark/bright duality of the films in the book. It seemed that chemistry in the movies went beyond horror versus comedy, but it was not clear how this played out in the language of film criticism. An examination of the film genres found in the various chapters (table 1) revealed that the most common genre in the dark side is thriller, not horror. In fact, horror is less common than drama. The analysis confirmed that the most common genre on the bright side was comedy, but additionally that the second most common was drama. Given that drama is found on both sides of our duality, the book's dominant genre duality seems to be thrillers versus comedies. Either someone is going to be killed, or the chemistry provides a firm foundation from which to launch amusing or satirical comment. If instead we take into account that, among all movies listed on the Internet Movie Database (www.imbd.com), there are many

Table 1. Genre analysis of the movies in each chapter[a]

Chapter	Chemical Theme	Movie Genre Signature
The Dark Side		
1	Jekyll and Hyde (9)	9 horror, 5 sci-fi, 4 drama
2	Invisible man (7)	6 sci-fi, 5 horror, 4 [black] comedy, 4 thriller
3	Chemical weapons (15)	8 thriller, 6 drama
4	Bad companies (12)	8 drama, 4 thriller
5	Addiction (11)	8 drama
The Bright Side		
6	Inventors (11)	8 comedy
7	Forensics (13)	7 drama, 7 mystery, 7 thriller, 5 action, 5 crime
8	In the classroom (11)	7 comedy, 4 sci-fi, 4 romance
9	Good researchers (12)	5 drama, 4 comedy
10	Drug discovery (15)	8 drama, 8 sci-fi, 6 horror, 6 comedy

[a] The genres were taken from the Internet Movie Database (www.imdb.com) in 2008. A "genre signature" is defined here as genres found in more than one-third of the movies in that chapter.

more dramas (121,000) and comedies (97,000) than romance (22,000), thrillers (18,000), horror (12,500), sci-fi (9,000), mystery (8,000), and biography (4,000), we learned that our "dark side" movies were rich in thrillers, horror, and sci-fi, whereas our "bright side" movies were rich in biography, mystery, and romance. This genre duality feels right in that there is an inherent danger to every discovery but it is accompanied by an element of excitement.

1

Dr. Jekyll's Mysterious Transformative Formula

MIRRORS AND CHIRALITY

"Jekyll and Hyde" is a phrase known to many, though few have read the short novella published in 1886. It is far more likely that people have encountered the phrase during conversation or in one of its numerous adaptations. In fact, the *Strange Case of Dr. Jekyll and Mr. Hyde* by Robert Louis Stevenson is the most adapted story of all time, even exceeding such texts as Mary Shelley's *Frankenstein*, Charles Dickens's *A Christmas Carol*, and Shakespeare's *The Tempest* (Rose 1996). The idiom "Jekyll and Hyde" usually refers to someone or something that manifests its opposite tendency in different contexts. Colloquially, it does not always carry an explicit chemical connotation. But, in the more than 100 stage, movie, television, and cartoon adaptations (for a continually updated list, see Dury 2006), Jekyll is nearly always transformed into Hyde after ingesting or injecting a chemical formula of his own manufacture. For this reason, it is the single most important example of chemical self-experimentation in the movies.

Nearly all of the dramatic Jekyll and Hyde adaptations have important scenes in which the mirror is used as a research tool (table 1.1). After Jekyll transforms into Hyde for the first time, he determines that the experiment was a success by looking into a mirror. He sees the monstrous Hyde in the reflection and knows that he, Jekyll, no longer looks like himself. It is very likely he no longer even feels viscerally like himself. The transformation scene, preceding the mirror scene, often shows Jekyll painfully grimacing, shaking, or groaning. The mirror scene is the point of full realization. We can conclude that Jekyll's mind, though now contained in the persona of Hyde for the first time, is still able to internalize this realization with a scientist's thinking process. As the story progresses, however, Hyde becomes increasingly more powerful and uses the mirror for self-satisfied confirmation that he has trumped Jekyll yet again.

The mirror is the axis on which the status of the Jekyll and Hyde character flips. The mirror scene initiates an understanding that Jekyll and Hyde function as a paired unit. Together they make a whole, yet each of them is a discrete physical entity in space and time, with competing interests. What is Dr. Jekyll's original intention when he designs

Table 1.1. The first mirror scenes in the Jekyll and Hyde films discussed in this chapter

Title (Year)	First Mirror Scene
Mary Reilly (1996)	13:00: Jekyll looks backward into bedroom cheval glass while asking Reilly to have Poole take it to the laboratory
Dr. Black, Mr. Hyde (1976)	23:30: Pride looks into bedroom wall mirror after first self-injection
I, Monster (1971)	26:00: Blake admires his reflection as he carries the mirror from the drawing room to his laboratory
Dr. Jekyll and Sister Hyde (1971)	24:45: Jekyll struggles to drawing room after first self-injection only to find the reflection of Sister Hyde
The Two Faces of Dr. Jekyll (1960)	1:14:30: Jekyll speaks to Hyde in small laboratory mirror as they each struggle for dominance
Dr. Jekyll and Mr. Hyde (1941)	36:00: Jekyll drinks potion, hallucinates, and then awakens to admire his reflection in a laboratory mirror
Dr. Jekyll and Mr. Hyde (1931)	5:00: As Jekyll leaves to give his speech at the medical college, he stops at hall mirror to straighten up
Dr. Jekyll and Mr. Hyde (1920)	25:00: After transformation, Hyde enters drawing room to look at himself in a mirror we do not see
Dr. Jekyll and Mr. Hyde (1912)	1:00: After first transformation, Hyde peers into small laboratory mirror

his experiment? In the 1931 Paramount Pictures version, Fredric March as Dr. Jekyll tells us in a lecture, "Man is not truly one, but truly two." He categorizes one side as noble and the other as basely impulsive. He further describes the sides as good and bad, respectively, and sees them as "chained together" in an ongoing struggle. He asks rhetorically how much better humans would be if the two selves were separated and the good self were allowed to be truly good, unencumbered by its evil counterpart. Dr. Jekyll seeks to separate the two selves that comprise one human being by utilizing the power of chemicals to affect a split. Thus, on its most primary level, the Jekyll and Hyde story illuminates the functioning dynamic of the pair and the concepts of symmetry and dominance.

There are pairs found in nature. In one of the "space arrangement riddles" of chemistry, this molecular phenomenon is called chirality (Brown 2003). Two chiral molecules form a pair called enantiomers, Greek for opposite parts (*enantios* + *mere*). The mirror is the central metaphor for understanding the structure and conformation of chiral molecules in three-dimensional space. What a mirror really does is interchange front and back (Close 2000). When the axis perpendicular to the mirror reverses, an imaginary mirror-image space comes into being. The form

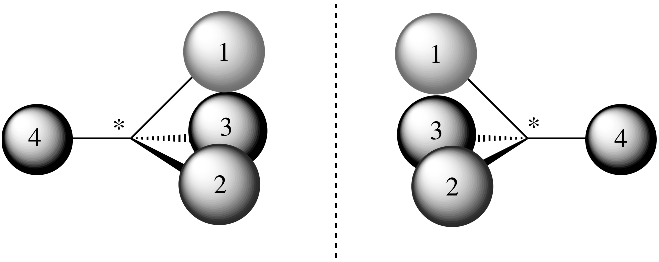

Figure 1.1. A chiral compound has a central atom (asterisk) attached to four different atoms or groups of atoms. Two compounds that are mirror images of one another are called enantiomers.

reflected in this space is geometrically equal but not congruent with its "real" counterpart (figure 1.1).

Chirality means "handedness"; chiral is from the Greek for hand (*kheir*). This term neatly conjures up our own body as a reference point for understanding. By invoking the bilateral, or two-part, asymmetry that is expressed in the external form of our own body, we see how fundamentally ingrained is left and right in the natural world. Consider our hands (or just as easily our two feet). Our pair of hands can be thought of as two three-dimensional solids of relative equality (Shubnikov and Koptsik 1974), but they are not identical because the left hand cannot occupy the same three-dimensional space as the right hand. One hand is not superimposable on the other; they do not have coincidence. It is only when the left hand is reflected on a mirror plane that it appears to have the same spatial orientation as the right hand. Our hands are similar yet also different in this important respect.

Chirality holds life on Earth in a profound handclasp of parity and privilege. Though the origins are not fully understood, biological life shows a definite bias in favor of one molecule over the other in a mirror-image pair. There is the maxim, however, that if it is possible for two opposite forms of a molecule to exist, these are rarely used simultaneously; organic life will make a single choice (Whyte 1975). The difference between left- and right-handed molecules is fundamental to the efficient functioning of biological life. The bias of a single handed-form over the other is present in the building blocks of protein, DNA, and polysaccharides (Bernal et al. 1972). In general, life uses only left-handed amino acids and right-handed sugars. A significant property of chiral molecules is optical activity, which is displayed in relation to the structural asymmetry of the individual molecule.

Is there an analogy from chirality that we can take to the movies? Hyde is conceived by Jekyll and then brought into physical being through experimental research that leads to the ingestion of a chemical substance. The mirror scene links Jekyll and Hyde together, giving us a striking mental image of a similar pair possessing an oppositional undertone. Constrained by the properties that comprise our three-dimensional world, the opposing forms of Jekyll and Hyde cannot exist simultaneously in physical space. One occupies real space, and the other imaginary space. We can further extend the analogy to say that since Jekyll and Hyde is an active, living character with an enantiomer form, only one side of his handed state will be expressed at one time. Which bias will get the "upper hand"? The resulting movie story lines utilize this dynamic tension to create screen versions that twist and turn the location, duration, and conformation of Jekyll and Hyde. We don't have to limit our discussion of chirality to analogies, however. We'll see in the next section how a chiral molecule may hold surprising significance for interpreting the Jekyll and Hyde tale.

This will be a book of correspondences, oppositions, and stresses on inflection. One depiction of chemistry will come face-to-face with another depiction of chemistry. In a broad sense, the movie screen is the mirror plane that reflects the constructs society brings to it. When Jekyll looks into the mirror and sees Hyde, he sees not only a transformation of his own making, but also a dilation on the scope of real and imaginary.

STEVENSON, HIS NOVELLA, AND THE CHEMISTRY OF THE HYDE FORMULA

Even though this first chapter is about the most referenced chemist in the movies, the dark Jekyll and Hyde movies have the least chemistry in them. Stevenson's 1886 novella is a mystery/detective story in which the reader doesn't know until the last chapter that Jekyll and Hyde are the same person. In his 1998 book about mad scientists, horror analyst David Skal says that the Jekyll and Hyde story "reflects the Victorian Era's dilemma vis-à-vis evolutionary theory: how to reconcile the human personality's higher and lower natures." He notes that this meshed well with Victorian interest in balancing scientific reductionism with the craving for spiritual transcendence.

Most classically horrific Dr. Jekylls are physicians carrying out pharmacological research with an unnamed compound that physically transforms them into someone who feels no remorse for the terrible acts he performs. We have a natural fear of the unknown that horror movies exploit. This is probably why most comedy Dr. Jekylls spend more film time naming and explaining the nature of their Hyde formulas than do the dramatic versions (see chapter 8 for two examples). Because the compound is not named in the original or in the dramatic adaptations, it becomes possible to transfer our anxiety about any new psychopharmaceutical to the Hyde compound. If Stevenson had named the active ingredient in the Hyde formula, the film adaptations might have told the tale of the chemical and not of the transformation. The work's lack of definitiveness on this point gives power to the many re-adaptations. The book and movies are tales of science anxiety, not science. Dr. Jekyll rashly decides to self-experiment with a new chemical, and the experiment goes awry.

On the other hand, some chemical and literary forensics allows us to identify the most likely candidates for the Hyde formula ingredients and even to speculate about the Hyde molecule itself. There is enough information provided in the novella to identify the "blood-red liquor" with near certainty. An examination of Stevenson's life allows us to speculate about the "unknown impurity." Together, this vastly enriches the scientific reading of this classic text by bringing its alchemical and gothic roots to the fore.

The Chemistry of the "Blood-Red Liquor"

From "Dr. Lanyon's Narrative," the penultimate chapter of Stevenson's novella (emphasis added):

> The powders were neatly enough made up, but not with the nicety of the dispensing chemist; so that it was plain they were of Jekyll's private manufacture; and when I opened one of the wrappers I found what seemed to me a simple crystalline salt of a white color. The vial, to which I next turned my attention, might have been about half full of *a blood-red liquor, which was highly pungent to the sense of smell, and seemed to me to contain phosphorus and some volatile ether.* At the other ingredients, I could make no guess.

From this list it appears that there are three components to the Hyde formula: the white crystalline salt, the blood-red liquor, and "other ingredients." The white crystalline powder is described in the next section, the blood-red liquor is identified in this section, and it is not necessary to describe the "other ingredients" because they are not used to make the Hyde formula. The color and smell of the "blood-red liquor" along with the specific mention of the element phosphorus suggests it is white phosphorus and gold chloride dissolved in carbon disulfide. Such a mixture produces a clear ruby red suspension of gold colloid particles. Carbon disulfide liquid was commonly used to dissolve compounds that weren't particularly soluble in water. Today, it has been replaced by solvents such as dimethyl sulfoxide (DMSO).

Phosphorus was one of the elements discovered by an alchemist, the German apothecary Henning Brand, in 1669. He concentrated gallons of urine and separated and reduced its components until he had a material that glowed while it combusted. There are two pure forms of phosphorus, white and red. The two forms differ in the way the phosphorus atoms pack together, but both must be kept from the atmosphere by storage in a solvent such as carbon disulfide. The two forms are nearly identical in their chemical reactivities; they are very strong reducing agents that react to form phosphate. The solvent carbon disulfide (S=C=S) gains the pungent odor of hydrogen sulfide (H_2S) as it decomposes to carbonylsulfide (O=C=S) in humid environments:

$$CS_2 + H_2O \rightarrow COS + H_2S$$

It is possible to make an even stronger alchemical connection. In 1857, Michael Faraday used phosphorus dissolved in carbon disulfide to reduce a yellow-colored gold chloride solution to make a ruby-colored suspension of gold nanoparticles: $Au^+ + e^- \rightarrow Au^0$ (Faraday 1857).

To achieve this alchemy, Faraday dissolved white phosphorus in "two or three times its bulk" of carbon disulfide, added a gold chloride solution that he "spread about by a glass stirrer, so as to form a flowing layer on the surface," collected the thin film onto a glass slide, and examined it under a microscope. He determined that it was metallic gold even though it was tinted pink, or rose, or ruby. The solution's color changed as the gold transformed from an ion to small metal particles. Faraday was so interested in the solubility of his colloidal gold in water that he did not provide an explanation for the change in color except to make the analogy with gold leaf (gold metal pounded into very thin layers), which has veins of red, blue, green, and violet. Today, we know that the different colors result from different-sized clusters of gold metal atoms, so Faraday's experiment is considered to be the birth of nanoscience.

In 2006, chemical historian Ryan Tweney reproduced Faraday's experiments and found that there was considerable skill involved in each step of the procedure (Tweney 2006). It has been established by other researchers that the gold nanoparticles are colored due to surface plasmon resonance (SPR) (Hu et al. 2006). SPR occurs because the atoms in the gold nanoparticles absorb only certain frequencies of light. The gold nanoparticles absorb and reflect green light, which means that these solutions allow ruby-colored light to pass through. Today we know that Faraday's gold nanospheres must have been about 50 nm in diameter. When that information is combined with gold's known molar mass (197.0 g/mol) and density (19.3 g/cm^3), it is possible to calculate that each 50-nm-diameter gold nanosphere contains about 4 million atoms of gold metal, n_{Au} (equation 1.1):

$$n_{Au} = \frac{6.022 \times 10^{23}\,\text{atoms}}{\text{mole}} \times \frac{\text{mole}}{197.0\,\text{g}} \times \frac{19.3\,\text{g}}{\text{cm}^3} \times \frac{4\pi(25 \times 10^{-7}\ \text{cm})^3}{3}$$

The Chemistry of the "Unknown Impurity"

Also from "Dr. Lanyon's Narrative" (emphasis added):

> "Have you a graduated glass?" he asked. I rose from my place with something of an effort and gave him what he asked. He thanked me with a smiling nod, measured out a few minims of the red tincture and added one

> of the powders. The mixture, which was at *first of a reddish hue*, began, in proportion as the crystals melted, *to brighten in color*, to effervesce audibly, and to throw off small fumes of vapor. Suddenly and at the same moment, the ebullition ceased and the compound *changed to a dark purple, which faded again more slowly to a watery green*. My visitor, who had watched these metamorphoses with a keen eye, smiled, set down the glass upon the table, and then turned and looked upon me with an air of scrutiny.

And from "Henry Jekyll's Full Statement of the Case," the final chapter (emphasis added):

> My provision of the salt, which had never been renewed since the date of the first experiment, began to run low. *I sent out for a fresh supply, and mixed the draught; the ebullition followed, and the first change of color, not the second;* I drank it and it was without efficiency. You will learn from Poole how I have had London ransacked; it was in vain; and *I am now persuaded that my first supply was impure, and that it was that unknown impurity which lent efficacy to the draught*.

When a few minims (i.e., a few drops) of a strong acid, base, oxidant, or reductant are added to a dry powdered compound, it will bubble and give off gases in a reaction. Ebullition is the term for a bubbling solid. The other key to solving Stevenson's chemical riddle is that very few pharmaceutical compounds change color when they effervesce. Tellingly, he wrote that when the unknown impurity is present, the solution begins red, brightens, becomes dark purple, and then fades to a watery green.

In September 1885, one month before Stevenson wrote his famous story, his physician Thomas Bodley Scott treated him with ergotine (Stevenson 1885; Goodwin 2005). Keeping this in mind, the next paragraphs reveal what might be the "unknown impurity." From age 9 until he died at age 44, Stevenson suffered from a disease that no doctor could correctly diagnose or cure. Since age 29 in 1880, he had the symptom of bleeding lungs and would often cough up blood (Booth and Mehew 1994–1995). This was so acute and recurrent that by 1884 his Edinburgh physician recommended he move to sunnier and drier southern England. This is how Stevenson, his wife Fanny, and her son Lloyd from a previous marriage came to live in Bournemouth from September 1884 to August 1887. It is during these remarkable three years and despite his now chronic coughing that he wrote some of his most memorable works: *The Child's Garden of Verses, Kidnapped, Prince Otto,* and *Strange Case of Dr. Jekyll and Mr. Hyde*.

Many contemporaries and biographers have logically concluded that Stevenson had tuberculosis. In 2000, however, Guttmacher and Callahan (2000) speculated that he actually suffered from a rare genetic disease called hereditary hemorrhagic telangiectasia (HHT). This disease is consistent with Stevenson's respiratory complaints since childhood, recurrent episodes of pulmonary hemorrhage beginning as an adult, and death at 44 from probable cerebral hemorrhage. They note that his mother died at 38 from an apparent stroke, that her father suffered from "a weak chest" even though he lived a long life, and that several of her siblings died young. The evidence against a diagnosis of tuberculosis is that Stevenson lived 15 years after the onset of the disease, and no one else in his household ever developed it. The evidence against HHT is that he is not reported to have had many nosebleeds, a classic trait of that disease. On the other hand, some descriptions of his bouts of spitting up blood could be interpreted as nosebleeds.

His Bournemouth physician Dr. Scott must have decided to give him ergotine because of its ability to constrict blood vessels. It had been known for centuries that when a woman ingested a small amount of ergot fungus during childbirth, she would begin contractions and subsequently suffer little postpartum bleeding. In 1842, the French physician Bonjean was hoping to discover the uterine-contracting compound by soaking ergot in water (Bonjean 1842). While his water extract was less active than the ergot itself, physicians and midwives used it right away as its taste was much less bitter. Bonjean established that the compound in his water extract contained nitrogen, so he named it "ergotine" (ergot + amine). Almost immediately, other chemists and physicians showed that Bonjean's ergotine was not a pure compound, but none of them were able to separate the mixture into its pure components. Their only separation tools were solvent extraction, crystallization, and distillation. In the following 100 years, better separation methods were developed, and all of the active ergot compounds were identified (figure 1.2). During this same time period, other researchers established that Bonjean's ergotine slowed the heart, contracted arteries, lowered body temperature, diminished reflexes, and caused short-term madness (i.e., was hallucinogenic)

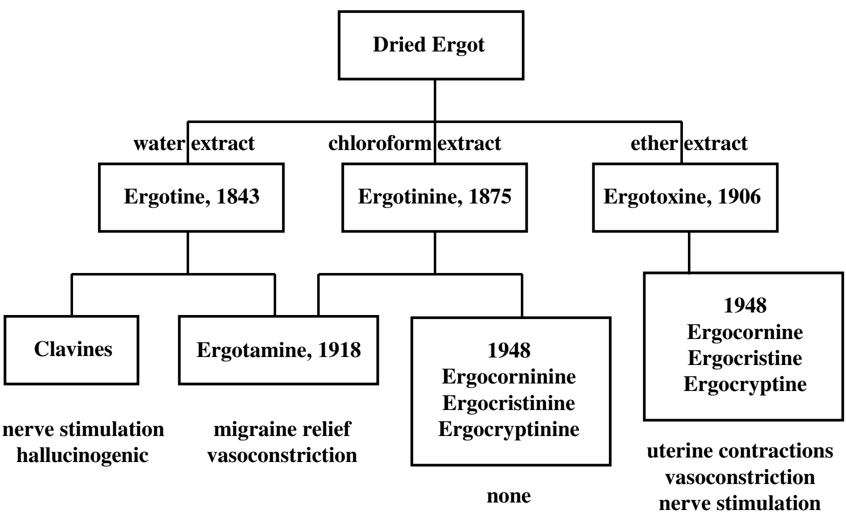

Figure 1.2. Purification outline for the ergot alkaloids.

at high doses. It is obvious that ergot is a "pharmacological toolbox" with many different compounds making up to 2% of its dry mass (Tudzynski et al. 2001).

In a letter written only weeks before Stevenson penned *Jekyll and Hyde*, his wife Fanny described him acting like a mad man after receiving treatment with ergotine to control his bleeding (Stevenson 1885). In 1948, ergotine was shown to be a mixture of water-soluble clavines and ergotamine. Clavines are the precursors of lysergic acid, and the most abundant examples are elymoclavine (figure 1.3), agroclavine, and lysergol. They are probably the major causative agent of convulsive ergotism, a type of ergot poisoning that causes repetitive and painful flexing of all the body's muscles that is sometimes accompanied by temporary madness (Schardl et al. 2006). A minor component of ergotine is the slightly water-soluble molecule named ergotamine. It was the first ergot compound to be isolated in pure form, a feat achieved in 1918 by Arthur Stoll at Sandoz Pharmaceutical in Basel, Switzerland (Stoll 1920). Ergotamine is widely used for its antimigraine properties even today. Therefore, our chemical sleuthing so far indicates that if Jekyll's "white crystalline powder" is the mixture called ergotine, then the "unknown impurity" is ergotamine. The color changes provide further evidence.

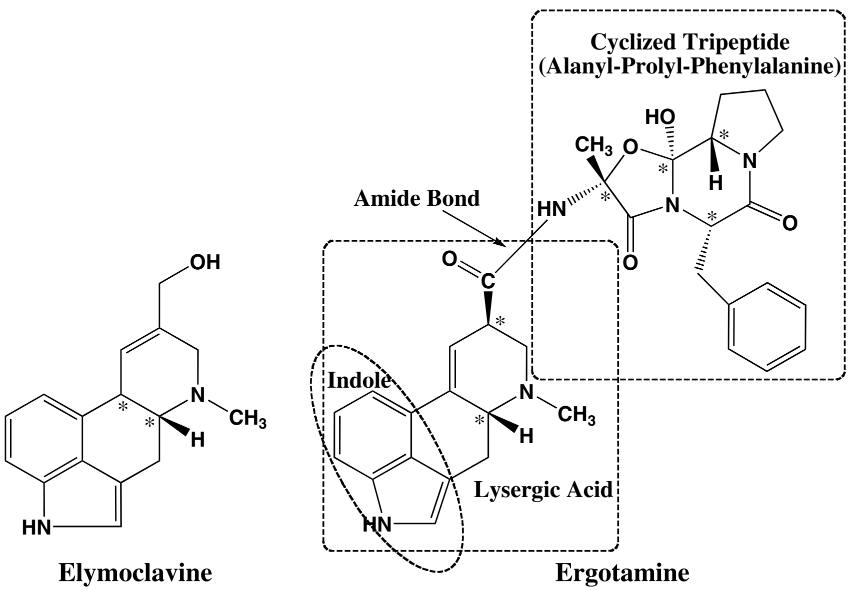

Figure 1.3. Elymoclavine and ergotamine are water-soluble ergot alkaloids that were likely components of Jekyll's "white crystalline powder." In these skeleton formulas, the lines represent the bonds between atoms, and carbon atoms are assumed to be at all unlabeled junctions between lines. Asterisks have been added to signify the chiral carbons.

In 1875, Charles Tanret prepared a chloroform extract of ergot that he called ergotinine but that was later shown to be a mixture of ergotamine-like molecules. More important, he also reported a simple colorful test for his ergot alkaloids (Tanret 1875). When he dissolved a few grams of his white crystalline powder in concentrated sulfuric acid, the solution was yellowish orange. The purer the alkaloid, the brighter the orange color. After a few hours, this solution gradually became violet blue. For at least the next twenty years, this chromogenic (color-producing) assay was used to determine the approximate amount of ergotamine-like compounds in ergot extractions. It would certainly have been the assay used by knowledgeable physicians in 1885. Did Dr. Scott show this assay to Stevenson before he treated him? There is no historical evidence on this point, but the description in Stevenson's novella suggests he did, although Stevenson masterfully embellished the color changes.

Unknown Impurity + Blood-Red Liquor → Hyde Formula

No real chemist has ever mixed ergotamine, the "unknown impurity," with phosphorus dissolved in carbon disulfide, the "blood-red liquor," so the identity of the Hyde formula is open to speculation. Although phosphorus is a strong reducing agent, it may not have much effect on ergotamine. It may simply react with the acidic solution to create hydrogen gas bubbles, or effervescence.

The chemical basis for Tanret's assay has never been determined, but it seems most likely that the strong sulfuric acid promotes dimerization at carbon 2 of the lysergic acid part (figure 1.4). Atmospheric oxygen that is

2

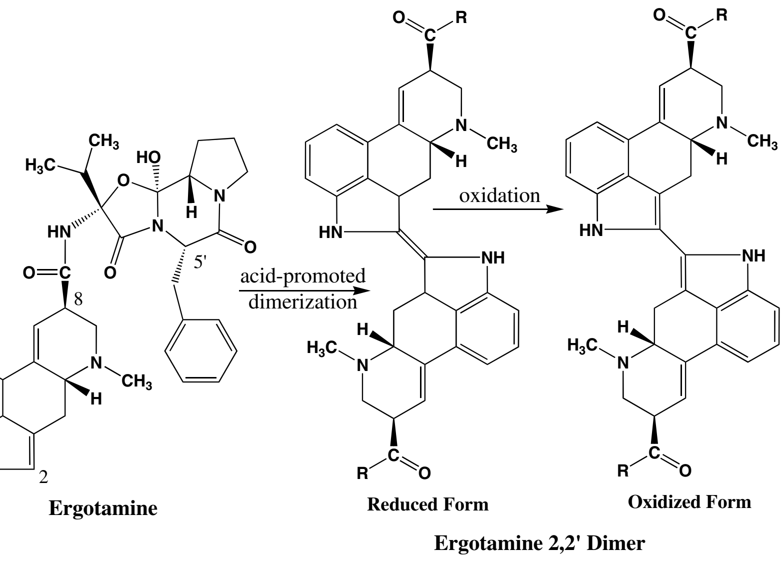

Figure 1.4. Proposed chemical reaction to create the Hyde formula.

dissolved in the solution is likely to cause subsequent oxidation. Both of these are reasonable assumptions because ergotamine contains an indole group (see figure 1.3). The indole group was first found in indigo dye, which is a dimer of indoles connected with a bond between their carbon 2's. The name "indigo" means Indian dye and was so named because it was originally cultivated in India by a method that was kept secret for centuries. Indigo has the interesting property that it is clear when reduced and dark blue as it slowly oxidizes by reaction with atmospheric oxygen. It is still used to dye blue jeans, except that the dye is now created synthetically.

Ergotamine dimerization in acid would be accompanied by a color change because it would increase the number of conjugated double bonds. The oxidation step may be slow, however. Since neither Jekyll nor Hyde ever waited hours for the color to develop, both of them must have ingested the reduced form. Even so, both the reduced and oxidized forms would be fluorescent and would give off a greenish blue color that Stevenson may have perceived as "watery green" (Stachel et al. 1996).

FROM ALCHEMISTS TO VICTORIAN GENTLEMEN SCIENTISTS

According to Rosslynn Haynes (1994), there are six recurrent types of scientists in literature and film: (1) the alchemist, representing the obsessed or maniacal; (2) the stupid virtuoso, representing the out-of-touch with the real world; (3) the unfeeling scientist who has reneged on human relationships and has suppressed human feeling; (4) the heroic adventurer who explores new territories and is a mental giant; (5) the helpless scientist who loses control over his own discovery; and (6) the idealist, who is the unambiguously acceptable stereotype.

These literary scientists emerged coincidentally with real scientists. Modern analytical science was set in motion by Isaac Newton's theories about the nature of gravity and light in the early 1700s. Newton's special knack was to model the ideal case mathematically and then to determine how closely the real situation resembled the theoretical. Using this method, he repeatedly demonstrated that there were natural laws. The immediate result was that Newton's mathematical relationships were put to practical use by engineers and caused many scientists to adopt his methods. Between 1830 and 1833, Charles Lyell created our modern understanding of evolution as he published his three-volume geological treatise that was filled with evidence. By 1859, the English public was so well read scientifically that the first edition of Charles Darwin's evidence-based *Origin of Species* sold out in one day. By the 1870s, professors at the universities of Oxford and Cambridge began teaching courses in science, and the scientific focus moved from the gentleman/scientist engaged in philosophical experiments to the academic scientist engaged in experimental empirical research. This is also when scientists began to specialize in various branches of science, becoming chemists, physicists, and the like.

The first major scientific medical discoveries were also made during the 1800s. The birth of chemical pharmacology began in 1817 when German pharmacist Friedrich Sertürner isolated morphine from opium (Sertürner 1817; Huxtable and Schwarz 2001). First, he soaked the opium in hot water to extract the morphine, and then he added ammonia to precipitate a white crystalline solid. It is also significant he performed tests on dogs and humans to show that the crystalline substance had the same pharmacological properties as the opium but that the nonextracted remainder did not. By 1827, Heinrich Merck of Darmstadt was selling morphine isolated using this method. Morphine was the first natural product, and it set off a wave of similar isolations: strychnine in 1818, caffeine in 1820, cocaine in 1860, and many, many others. Additional medical breakthroughs included vaccination in 1796 by English physician Edward Jenner, the stethoscope in 1816 by French physician Rene Leannec, general anesthesia in 1847 by American dentist William Morton, antisepsis in 1865 by English physician Joseph Lister, the germ theory of disease by German physician Robert Koch in 1877, and the hypodermic needle in 1853 by French physician Charles Pravaz.

PSYCHOLOGY OF OPPOSITIONS

There is a transformation scene in the final minutes of *I, Monster* (1971). The Hyde character Mr. Blake is about to inject his formula. We see his shadow looming darkly in silhouette against the paper-patterned wall of Lanyon's rooms, one arm greedily outstretched to receive the needle. The fingers of Blake's hand, elongated in the distortion of cast shadow, splay exaggeratedly as the formula begins to take effect. Soon afterward his movements cease and the shadow figure reanimates in calm repose as the Jekyll character, Dr. Marlowe.

I, Monster is one of the most psychologically overt movie interpretations of the Jekyll and Hyde story. Dr. Marlowe is an analytical psychologist of the Freudian school. No longer a tale from the Victorian era, this story is set in 1906, firmly in the new twentieth century. It is informed by the ideas and methods used in the nascent science of modern psychology, which originated in continental Europe in the late 1800s and spread in influence throughout the world. With it came the promise of new understandings about the human mind and the celebrated names of Freud and Jung.

Jungian psychotherapist Barbara Hannah said that Robert Louis Stevenson had "extraordinary insight into the unconscious—far beyond that of his time." He would have been singularly gifted to practice this new analytical psychology, had its methods been known during his lifetime (Hannah 1971). In devising the bifurcated Jekyll and Hyde character, Stevenson aptly illustrates the problem of the intimate relationship of the shadow to the self. It is a characterization that anticipates the work of Jung, Freud's talented student, on the problem of integrating the *personal shadow* into the larger whole of the *self.* In Jung's psychology, the shadow represents the unrecognized, disowned, animal-like personality rejected by the ego. It appears personified in a figure of the same sex as a dark mate who accompanies and clings to its lighter half (Avens 1977). Mythological and cultural counterparts to Hyde–Jekyll are Cain–Abel, Set–Osiris, and Mephisto–Faust. In Jung's scheme, finding the right relationship to the shadow includes acknowledgment and acceptance of it without identifying with it. Failure to do this puts the person at risk of falling under the shadow's spell, with disastrous results—the very thing that symbolically happens to Dr. Jekyll.

While Jung's psychoanalysis is concerned with the present and how it gives rise to future development in an individual, Freud's can be characterized as archeological (Salman 1997). Referred to as depth psychology, Freud's analysis probes into the personal narrative of an individual's past to uncover repressed authentic desires, often sexual in nature. There is a species level of survival that requires an individual to oppressively conform to societal constraints, causing one to come into conflict on a daily basis with the selfish individual need to feel pleasure and avoid pain. Since this conflict is taking place at the unconscious level, it is revealed in "symbolic disguise" in dreams (Robinson 2007). The dream sequence in *Dr. Jekyll and Mr. Hyde* (1941) represents Hyde's driving instinct of self-gratification as one of surreal sexual perversity. He is the whip-happy coachman being pulled by the two women in his life.

Let's return to the wallpaper on which Blake's shadow is projected in *I, Monster.* What is the color and texture of the background psychological scene in the Victorian era? Stevenson's novella was written in 1886, before analytical psychology emerged as an influential practice in Britain. The word "psychology" is Greek for "soul discourse," and one of the main threads of psychological argument in 1850–1880s Britain concerned itself just with this "psychology of the soul" (Rylance 2000). Proceeding from a view of creation that was pyramidal in scheme, this discourse privileged civilized man with "special dignity." Although human, women and so-called primitives occupied a lower place in the hierarchy. This creation-view, framed in higher/lower pairings, segregated mind/body functions. They were separate and not equal; each had their place. The "faculty psychology" in currency at the time compartmentalized and categorized human abilities. Higher faculties, such as reasoning and moral ability, resided in the brain. Lower instinctual, animalistic faculties were to be found in the body. This is the cultural framework that formed our Dr. Jekyll. We find him in the 1931 movie version lecturing on man's "double being," describing man as "truly two."

Dr. Jekyll's intellectual and scientific exploration into human nature and how to improve it corresponds to the progressive temper of the age.

Historian Walter Houghton defines the Victorian Era as an "age of transition" with the change inherent in this transition possessing a dual aspect, that of destruction and reconstruction (Houghton 1957). The old, rigid, order of doctrines and institutions was being replaced by a new order, one fueled by an expansion of knowledge of all kinds, especially scientific. The optimistic positivism of this new order had its own nagging shadow, however. A pessimistic specter of doubt began to grow out of the sense that beliefs were not on solid footing.

And why? The hierarchical scheme of creation had a foil of its own that would come directly out of the Darwinian theory of natural selection through random variations. As Stevenson scholar Julia Reid points out, there was no consensus in the late Victorian era that evolutionary progress was inevitable; unpredictability and extinction were part of natural selection, too (Reid 2006). The question became one of direction: If humans could evolve, could they devolve, as well? The Victorians had a "violent fear of contamination" (Rylance 2000), and the understanding that human nature had prehuman origins was unsettling. Stevenson's creative genius exploits the "friction and dissention" in the evolutionary thought of the time (Reid 2006). His simian Mr. Hyde is locked in a Darwinian struggle for survival of the fittest with the refined gentleman Dr. Jekyll. Who will win?

THE ARCHETYPE MOVIE: *DR. JEKYLL AND MR. HYDE* (1931)

Distribution company: Paramount Pictures
Director: Rouben Mamoulian
Screenwriters: Percy Heath and Samuel Hoffenstein, adapted from the screenplay for *Dr. Jekyll and Mr. Hyde* (1920)
Short summary: Physician Dr. Henry Jekyll develops a drug to separate the good and evil sides of man and then self-experiments

Plot description: Dr. Henry Jekyll (pronounced Jee-kill in this version and played by Fredric March, who shared the Academy Award for Best Actor for his performance) is a brilliant physician who spends his days giving free medical care to the poor and his nights working impetuously in his dungeon-like laboratory. He is engaged to Muriel Carew (Rose Hobart), the daughter of Brigadier General Danvers Carew (Holliwell Hobbes). Carew greatly disapproves of Jekyll's contempt for the social conventions of the upper classes, so he decides to cool his daughter's relationship by taking her on a several-months-long trip to Europe. In her absence, Jekyll decides to self-experiment with his formula, which leads him to an encounter with "Champagne Ivy" Pearson (Miriam Hopkins), a singer at the local tavern. Dr. Lanyon (Holmes Herbert) is Jekyll's best friend and the voice of the scientific establishment that Jekyll ignores but upon whom he relies.

The movie opens from Jekyll's point of view and continues from this perspective until he begins his lecture at St. Simon's University. As he leaves his home, he stops to adjust his tie in a mirror and we see him for the first time. After he begins speaking, we see him from the point of view of his audience, and the viewer becomes typically omniscient thereafter. The opening line of his lecture is: "Gentlemen, London is so full of fog that it has penetrated our minds, set boundaries for our vision." He then says he has analyzed the human psyche and found that "man is not truly one, but truly two." One is noble and good, while the other is animal-like and bad. He ends his lecture by saying, "I have found that certain chemicals have the power…" which fades into the voices of young men delighted by the beard-pulling lecture and an older physician voicing disgust with Jekyll's priorities.

In the next scene, we see bubbling apparatus that is worthy of a well-funded alchemist (figure 1.5). Jekyll rapidly and carelessly makes

Figure 1.5. Dr. Jekyll (Fredric March) is overshadowed by his chemical apparatus.

a solution while keeping notes in a book. After he adds a drop of something to the solution in his graduated cylinder, he determines that it works by examining a drop of it under a microscope. Before he brings the formula to his lips, he locks the door and writes a quick note to Muriel to tell her how much he loves her. He stands in front of the mirror as he drinks the clear formula. He clutches his throat and his skin darkens before he falls out of view of the mirror. When he rises, the room swirls around him and scenes from the previous conflicts are replayed. He groans, the image blurs, and he breathes like a monkey. When it is over, he is pleased with his appearance in the mirror and exclaims, "Free, free at last" while he stretches as though he were aching to go somewhere.

His future father-in-law objects to Jekyll's lack of propriety and all the time he spends with patients who can't pay for medical services. To cool their relationship, Carew takes his daughter on a long trip to Europe. This is the trigger for Jekyll to take the formula for the second time. As Hyde, he begins a relationship with a Music Hall girl named Champagne Ivy to whom Hyde is very cruel. After he kills her, the police almost catch him so he vows never to take the formula again. While on his way to Muriel's house as a reformed man, he passes through the park and sees a cat stalking a songbird. The off-screen violence causes him to transform spontaneously for the first time. He runs home, but the butler Poole won't let the stranger Hyde into the house. So, Hyde writes a note to his friend Lanyon asking him to retrieve some items from Jekyll's lab and to bring them to Lanyon's house. The bottom of the note indicates to take vials marked A.H.S.T.R.M. [Note from the authors: The meaning of the letters is obscure. If you, dear reader, can solve this mystery, please send us a note.] After observing the transformation and hearing Jekyll's confession, Lanyon convinces Jekyll he must do the right thing. Jekyll breaks off his engagement with Muriel, becomes agitated, transforms into Hyde, and kills her father. The police chase him to Jekyll's laboratory, where they shoot him, and the movie ends as he reverts in a series of dissolves from Hyde into Jekyll.

Commentary: This is considered to be the best Jekyll and Hyde adaptation and ranks among the best films in this book. It is unusual in many ways. It was produced by Paramount rather than Universal, which produced both *Dracula* (1931) and *Frankenstein* (1931) in addition to most of the other classic horror films. It was directed by Rouben Mamoulian, who had directed only a few films before this one but who had been a very successful opera director. It stars Fredric March, who had played only light romantic comedy prior to this film. March shared the Best Actor Award at the fifth annual Academy Awards for his performance. He remained the only actor to win for performance in a horror film until 1982, when Anthony Hopkins won for *Silence of the Lambs*. A number of the visual puns in Jerry Lewis's *The Nutty Professor* (1963) (see chapter 8) can be fully appreciated only by watching the 1931 version.

When MGM decided to produce its 1941 version, it purchased all of the rights to the 1931 version and placed the master copy in its vault. Archivist Raymond Rohauer discovered those prints in 1967 and presented a copy to director Rouben Mamoulian. Thus began its second life in revival theaters and on television. In 1989, MGM/UA Video restored 6 minutes of scenes that had been cut from the movie and released the film on video. You'll know you are watching the restored version if the movie begins with a subjective camera shot of Jekyll playing an organ.

An important note: What strikes one in viewing the Jekyll and Hyde movies is their misogynistic bent. It is difficult to stomach such violence against women and disturbing that this story theme has been gratuitously adapted so many times without scrutiny. An early exception was the 1913 King Baggot silent version, in which Hyde's violence was solely directed toward boys and men. This version was thought to be "lost" until recently and has now been accepted into the National Film Registry of the U.S. Library of Congress because of its social and historical significance.

THE DRAMATIC JEKYLL AND HYDE ADAPTATIONS

Mary Reilly (1996)
Distribution company: TriStar Pictures
Director: Stephen Frears
Screenwriter: Christopher Hampton, adapted from the same-titled 1990 novel by Valerie Martin
Short summary: Devoted housemaid Mary Reilly is capable of loving the retiring Dr. Henry Jekyll and the evil Mr. Edward Hyde
MPAA rating: R

Plot description: Housemaid Mary Reilly (Julia Roberts) spends her long workweeks scrubbing floors and carrying food trays in the home of the physician Dr. Henry Jekyll (John Malkovich). Just as Reilly and Jekyll find they are attracted to one another despite their different social classes, the younger and more vibrant Mr. Edward Hyde (Malkovich again) appears in the home as Jekyll's assistant. Reilly is initially repelled by Hyde's aggressive behavior, but her continued presence seems to calm him, and she grows to like him. At one point, Jekyll asks whether she would want to be able to act without consequences, and she says that she doesn't believe in actions without consequences.

In the 14-minute scene beginning at 1:34:30, Hyde explains to Reilly that Jekyll tested two drugs but the cure "took an unexpected form—me." Hyde was able to come back without injection because he has the stronger personality. Just then, Jekyll emerges after a struggle and sends Reilly to his laboratory for some chemicals. She takes a case from a cabinet to Jekyll/Hyde off-screen and he grabs it. Jekyll emerges and tells butler Poole (George Sheen) that he must go to Finlay's: "Wait while they