CONTENTS

	Prologue	1
1	Stoppard: The Incline from Thinking to Feeling	16
	Albert's Bridge	24
	Rosencrantz and Guildenstern Are Dead	29
	Jumpers	37
	Hapgood	46
	Arcadia	61
2	Jarry and Witkiewicz: Geometry of a New Theater	74
	Euclid's *Elements*	80
	Ubu Roi and *Ubu Cocu*	87
	Tumor Brainiowicz	99
	Non-Euclidean Geometry	105
	Gyubal Wahazar	113
	The Water Hen	119
3	Beckett: The Language of Incompleteness	129
	Murphy and *Watt*	135
	Endgame	146
	Russell's Paradox	156
	Film and *Not I*	160
	Principia Mathematica	169
	Quad	178

4 Dürrenmatt, Frayn, and McBurney: The Shape of Content 186
The Physicists 189
Copenhagen 202
A Disappearing Number 219

5 Stoppard: The Logic of Self-Conscious Theater 235
Peano Arithmetic 238
The Real Inspector Hound and Other Plays 244
Dogg's Hamlet and Gödel's Code 253
The Real Thing 264
The Hard Problem 272
The Invention of Love 278

6 Whitemore, Wilson, and Mighton: The Dramatic Life of Alan Turing 284
Breaking the Code 286
The Universal Machine 294
Breaking the Code, Continued 304
Lovesong of the Electric Bear 314
Half Life 329

7 Auburn: Beautiful Proofs 336

Acknowledgments 347
Notes 351
Bibliography 371
Index 381
Color Plates follow page 234

1

Stoppard: The Incline from Thinking to Feeling

> I keep trying to find a play about mathematics. There is one somewhere but I can't find it.
>
> —TOM STOPPARD, FROM A 1985 LETTER

THE CURTAIN rises in the opening scene of *Arcadia* on the drawing room of the stately Coverly manner. The year is 1809. Thirteen-year-old Thomasina Coverly scribbles in her lesson book while her tutor, recent Cambridge graduate Septimus Hodge, sits at a distance ignoring his pupil. Thomasina is supposed to be tending to her daily algebra assignment, but stronger forces are at play and she finally breaks the silence.

> THOMASINA: Septimus, what is carnal embrace?
> SEPTIMUS: Carnal embrace is the practice of throwing one's arms around a side of beef. (2)[1]

Thomasina reports that she has overheard the house staff gossiping that "Mrs Chater was discovered in carnal embrace in the gazebo," and she has come to her trusted tutor for enlightenment. Septimus, meanwhile, is eager to have the morning to himself. To that end, he has given Thomasina the task of finding a proof for Fermat's Last Theorem, "a problem that has kept people busy for 150 years," but he quickly finds out that mathematics is poor competition for carnality in the battle for the attention of a thirteen-year-old. As clever as she is curious, Thomasina is not completely satisfied with Septimus's various explanations and, detecting his evasions, she eventually backs him into

"Septimus, what is carnal embrace?" *Arcadia*; Emma Fielding (Thomasina), Rufus Sewell (Septimus); Royal National Theatre, 1993. © Fritz Curzon / ArenaPAL.

a rhetorical corner. "I don't think you have been candid with me Septimus," Thomasina insists. "A gazebo is not, after all, a meat larder."

SEPTIMUS: I never said my definition was complete.
THOMASINA: Is carnal embrace kissing?
SEPTIMUS: Yes.
THOMASINA: And throwing one's arms around Mrs Chater?
SEPTIMUS: Yes, now, Fermat's last theorem—
THOMASINA: I thought as much. I hope you are ashamed.
SEPTIMUS: I, my lady?
THOMASINA: If *you* do not teach me the true meaning of things, who will?
SEPTIMUS: Ah. Yes, I am ashamed. Carnal embrace is sexual congress, which is the insertion of the male genital organ into the female genital organ for 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.
(*Pause.*)

THOMASINA: Eurghhh!
SEPTIMUS: Nevertheless, that is the theorem.
THOMASINA: It is disgusting and incomprehensible. (3)

A Truly Marvelous Proof

Arcadia premiered at the National Theatre in London on April 13, 1993. Two months later, at the Isaac Newton Institute in nearby Cambridge, Andrew Wiles went public with an actual proof of Fermat's Last Theorem. This was almost certainly the first time a mathematics conference had any direct bearing on events at the National, but Wiles's surprise announcement was international news, and it sent playwright Tom Stoppard scrambling to update the program for his new play.

In 1993, Fermat's Last Theorem was the most famous unsolved problem in mathematics. Its fame was due in part to the ease with which it could be posed—Septimus's one sentence summary is perfectly accurate—and in part to its storied history. Around 1630, the great French mathematician Pierre de Fermat was studying a personal copy of an ancient text called *Arithmetica*, written in about 250 CE by Diophantus of Alexandria. The text is essentially a collection of exercises and examples illustrating properties of integers, and one in particular caught Fermat's attention. Problem 8 in Book II asks the reader "to divide a given square into two squares." Fermat, like most of us, was familiar with the Pythagorean Theorem, which states that if x and y are the lengths of the legs of a right triangle and z is the length of the hypotenuse then

$$x^2 + y^2 = z^2.$$

Keeping in mind that numbers in *Arithmetica* were implicitly understood to be whole numbers; i.e., 0, 1, 2, 3, . . . , Diophantus's challenge was equivalent to asking whether there existed a right triangle with integer length sides. Such examples were well known; e.g., $3^2 + 4^2 = 5^2$ or $5^2 + 12^2 = 13^2$. The real interest originated from Fermat's generalization of Problem 8. Appended to this problem in his copy of *Arithmetica* is Fermat's now infamous marginalia:

> On the other hand it is impossible to separate a cube into two cubes, or a biquadrate into two biquadrates, or generally any power except a square into two powers with the same exponent. I have discovered a truly marvelous proof of this, which however the margin is not large enough to contain.[2]

"Biquadrate" refers to a fourth power. Thus, what Fermat claims is that the equation

$$x^n + y^n = z^n$$

has no integer solutions when n is any value bigger than two.

Needless to say, Fermat never supplied this "truly marvelous proof" in some other more spacious forum, and so resolving Fermat's claim, with either a proof or a counterexample, became an open question for the mathematical community that increased in stature every year it went unanswered. By 1809, when the fictional Thomasina was assigned the problem, the great Swiss mathematician Leonard Euler had provided a mostly satisfying proof for the case when $n = 3$ and Sophie Germain, a rare example of a nineteenth-century female mathematician, was solidifying her reputation by making significant progress on a large number of other cases. It is widely assumed that Fermat did not have the general proof he boasted about in his margin note, but he is credited with providing the argument for the case when $n = 4$ before he died. For three and a half centuries, mathematicians from around the world chipped away at Fermat's riddle, which is why Princeton mathematician Andrew Wiles decided it was best to work on the problem in secret to avoid the inevitable admonition he would have received from his colleagues that he was wasting his time. Even the title of his Cambridge lecture did not give away the surprise. When Wiles finally made the announcement that he had found a proof for Fermat's Last Theorem, the shock waves that rippled out from the Newton Institute were powerful enough to prompt the *New York Times* to run the front-page headline, "At Last, Shout of 'Eureka' in Age-Old Math Mystery."

You Cannot Stir Things Apart

Stoppard does not center the plot of *Arcadia* around the premise that Thomasina miraculously discovers a proof for Fermat's Last Theorem, but he does make her into a prodigious mathematician in a very different way. Later in the opening scene we get some additional evidence that *Arcadia* is more than just a comedy about the carnal escapades of the British aristocracy:

> THOMASINA: When you stir your rice pudding, Septimus, the spoonful of jam spreads itself around making red trails like the picture of a meteor in my astronomical atlas. But if you stir backward, the jam will not come together again. Indeed, the pudding does not notice and continues to turn pink just as before. Do you think this is odd?

SEPTIMUS: No.
THOMASINA: Well, I do. You cannot stir things apart. (5)

This image of increasing entropy—of the inevitable and irreversible rise of disorder in any closed system—serves as a compelling illustration of the Second Law of Thermodynamics, a principle of physics that did not get fully articulated until the middle of the century. From this exchange we get the sense that Thomasina possesses not only wisdom beyond her years but insight beyond her era. The classically trained Septimus makes a sincere attempt to be a proper tutor to Thomasina, but she quickly grows restless with his Greek geometry and Fermatian number theory and sets off to invent a new kind of mathematics that can more accurately capture the jagged and unpredictable contours of nature. "Mountains are not pyramids and trees are not cones," Thomasina complains when faced with the prospect of learning more of Euclid's *Elements*. "If there is an equation for a curve like a bell," she says on a different occasion, "there must be an equation for one like a bluebell, and if a bluebell, why not a rose? Do we believe nature is written in numbers?" (37)

What Stoppard has in mind for his young prodigy is the twentieth-century branch of mathematical science that falls under the general heading of chaos theory. As her particular project, Thomasina sets herself a task in the subfield of fractal geometry. Taking a leaf from an onstage apple, Thomasina declares to Septimus that she "will plot this leaf and deduce its equation. You will be famous for being my tutor when Lord Byron is dead and forgotten." (37) A century and a half before mathematician Benoit Mandelbrot coins the term "fractal," Thomasina fills her lesson books with strange looking equations that will ultimately require a computer to be properly realized, along with an endearing note to future scholars:

> I, Thomasina Coverly, have found a truly wonderful method whereby all the forms of nature must give up their numerical secrets and draw themselves through number alone. This margin being too mean for my purpose, the reader must look elsewhere for the New Geometry of Irregular Forms discovered by Thomasina Coverly. (43)

There Is One Somewhere

Euclidean geometry, fractal geometry, chaos theory, the Second Law of Thermodynamics, Fermat's Last Theorem. Before 1993 there were no examples of broadly successful plays that explicitly engaged this much mathematical

content, but *Arcadia* was immediately recognized as something extraordinary. Having authored over forty scripts during the previous three decades, Stoppard was viewed as one of the leading playwrights of his generation, and many people who knew his work well were claiming that *Arcadia* was his best.[3] "A perfect marriage of ideas and high comedy," wrote the *Times*. The *Daily Telegraph* called it "a masterpiece." The success of Stoppard's play put mathematics onto the pages of the arts section, and two months later Andrew Wiles moved it to the front page, above the fold. Pinpointing cause and effect is difficult, but this one-two punch of public acclaim coincided with a shift in the relationship between mathematics and popular culture. In the years after *Arcadia*, writers were increasingly amenable to incorporating mathematics in plays, novels, film, and television.

Responding to the rush of positive reviews in 1993, Stoppard acknowledged that something special had occurred with his latest play. "I feel for once that I stumbled onto a really good narrative idea. *Arcadia* has got a classical kind of story and, whether we are writing about science or French maids, this whole thing is about storytelling first and foremost."[4] What Stoppard was hinting at is that *Arcadia* was groundbreaking, not so much because it contained a great deal of mathematics, but because it made the mathematics integral to the play's emotional arc. What is missing from Stoppard's comments is any indication about how this merging of mathematics and storytelling was carried out. Why had no one done this before?

The attempt to weave mathematics into the plot of *Arcadia* was not a one-off idea for Stoppard. Early in his career, he acquired a reputation as a playwright of ideas. These ideas were in no way confined to science and mathematics. History, art, and politics are ubiquitous themes in Stoppard's writing, but Stoppard was perfectly willing to include mathematics in his palette alongside these other more traditionally acceptable motifs. This was true from the outset. The plot of the early radio play *Albert's Bridge* turns decisively on the details of a simple optimization problem. Probability makes an appearance in Stoppard's breakthrough play *Rosencrantz and Guildenstern Are Dead*. In *Jumpers*, the highly anticipated follow-up to *R&G*, Stoppard again mined mathematics to give the play some intellectual breadth.

As Stoppard's career progresses, the nature of the mathematics grows more sophisticated, as does the way he leverages it within the framework of the script. While early on, mathematics appears whimsically, it eventually becomes a point of focus for the playwright. "I keep trying to find a play about mathematics," he wrote to a friend in 1985. "There is one somewhere but I

can't find it."[5] While on the surface it may seem as though the central challenge is transporting technical ideas onto the stage without the burden of too much didactic luggage, the revelation of Stoppard's journey is that success depended on something else entirely. The intellectual heft he might give his plays by accessing the largely untapped terrain of mathematics would all be for show unless he could find a beating heart somewhere in the austere headiness of the theorems. He had to make the mathematics accessible, he had to make it authentic, and then he had to make it matter just as authentically on a personal level. This last trick was the crucial one and the most elusive. For many, including Stoppard, the allure of mathematics is its propensity for certainty, which is why a search for the humanity of mathematics sounds so incongruous. It's also why wedging a description of Fermat's Last Theorem up against the definition of carnal embrace generates such a hearty laugh. Sex is the opposite of math, or so their respective reputations would suggest. To find his math play, Stoppard would have to flip this public perception on its head, a challenge that required venturing beyond the predictable certitude of traditional algebra and geometry to find a more romantic incarnation of mathematics in the service of paradox and unpredictability.

So what kind of education might lead to an artistic sensibility like Stoppard's—one that saw as much dramatic potential in fractals and Fermat's Last Theorem as it did in poetry and politics? Given his rogue multidisciplinary disposition, it's a bit stunning and also, somehow, perfectly obvious that Stoppard never attended university. Dropping out of school at age seventeen, this highly decorated English playwright did not start out as an intellectual by any traditional definition. In fact, he did not start out English either.

A Bounced Czech

Tom Stoppard was born Tomáš Straüssler in July 1937. His parents, Marta and Eugen Straüssler, were settled in the town of Zlín in what was then Czechoslovakia. The year Stoppard was born, the Nazi threat was looming, and the Munich agreement of 1938 to give Hitler the Sudetenland fully unleashed the forces of anti-Semitism. Stoppard's father was an unobservant Jew and his mother's family had long ago converted to Catholicism. These details were irrelevant in the current political climate, and Stoppard's parents began to search for a way out. Somewhat miraculously, the Straüssler family managed to escape Czechoslovakia for Singapore in April 1939 under the pretense of a job transfer. All four grandparents stayed behind and would die in the Holocaust.

Singapore provided only a temporary respite. Over the next two years, Stoppard and his older brother Petr (who would later become Peter) learned some rudimentary English while living among the British in what was a tropical trading crossroads of Southeast Asia. By late 1941, however, Japanese bombs began to fall on the city, and in January of the following year, Stoppard boarded a ship in the dark of night with his mother and brother bound for Australia. Eugen Straüssler was a doctor who nobly stayed behind in Singapore to volunteer his services as part of the local defense effort. When he finally managed to secure passage on a departing ship some two weeks later, his vessel was attacked and destroyed by Japanese aircraft. The three surviving members of the Straüssler family, meanwhile, transferred midjourney to a ship bound for India and arrived in Bombay in February 1942.

From the time Stoppard was five until he was eight, his family lived in the city of Darjeeling, safely tucked up against the Himalayan Mountains. The boys attended an English-speaking school while their mother took a job as a clerk in a local shoemaking factory. In 1945, Marta Straüssler married a British army officer—Major Kenneth Stoppard—and soon the family was once again on the move, this time to England. Tomáš Straüssler legally changed his name to Tom Stoppard, and the young boy who had already lived in three countries finally found one he was able to call home.

Partly at his traditional stepfather's insistence, and partly of his own volition, Stoppard tried valiantly to shed his outsider status. In many ways he succeeded. He immediately took to the pastoral British landscape, and he has always maintained that English is his first language.[6] His mother took pains to sequester the family's refugee history from her boys, and both received fairly typical English prep school educations at Pocklington Grammar School in Yorkshire. Stoppard was a good student, although not distinguished in any particular way. He focused mostly on classics and history, taking some standard courses in mathematics and science but nothing beyond what was required. He did not participate in theater other than trudging through the requisite Shakespearean texts in his English classes, an experience he claims was uninteresting to him at the time.[7] His two passions at Pocklington were the debate society and the cricket team, both of which would become regular motifs in his playwriting career.

When it came time to decide between the university-bound track or wrapping up his education and heading into the professional world, Stoppard eagerly chose the latter. Still three years short of his twentieth birthday, he moved to Bristol, the town where his mother and stepfather were currently living, and took a job as a journalist writing for various local newspapers

about everything from car accidents to art openings. Stoppard enjoyed the writing but would later admit to some significant journalistic shortcomings. "I wasn't much use as a reporter," he said in a 1967 interview, "I felt I didn't have the right to ask people questions." This hesitancy led to some early experience writing fiction. "It was OK when [the articles] didn't use a photograph," he confessed. "I just sat in the canteen and made up quotes from people who always lived in one of Bristol's longest streets."[8] Among his many journalistic duties in the early years was serving as the second string theater reviewer, a task he enjoyed. Theater was undergoing something of a heyday in England at the time. Harold Pinter, John Osborne, and Samuel Beckett were contributing to a vibrant atmosphere that captured more and more of Stoppard's imagination. Around 1960, the twenty-three-year-old journalist made the decision that a career critiquing plays wasn't enough—he wanted to write them.

Albert's Bridge

Hear that, George? The City Engineer's figures are a model of correctitude.

—CHAIRMAN, FROM *ALBERT'S BRIDGE*

The early 1960s for Stoppard were a balancing act between freelance journalism to avoid poverty and hocking his scripts for stage, radio, and television. Stoppard's first modest success was late in 1961 when his stage play, *A Walk on the Water*, garnered enough interest that a production agency paid him 100 pounds for an option on the work. Although the agency did not ultimately produce it, a performance was eventually filmed for British Independent Television in 1963. In the meantime, Stoppard published a few short stories and authored several short radio plays that managed to find their way into the BBC's programming rotation. In 1964, Stoppard received a grant to attend a five-month playwriting workshop in Berlin during which he gave most of his attention to a work in progress with the title *Rosencrantz and Guildenstern Meet King Lear*. A public reading of this twenty-five-minute, one-act pastiche did not generate much enthusiasm among those who saw it, including its author. It was also around this time that Stoppard signed a contract to produce a novel. The common denominator in all of these projects was a sense of general ambition to secure a career as a writer in some form and a legitimate need for financial security. Stoppard was routinely in debt to anyone who would lend him money.

At this early stage in his career, the majority of Stoppard's work that made it to production was written for radio. With the limitations of the fifteen- and thirty-minute time slots of the BBC sound stage serving as catalyst for his creative imagination, Stoppard honed his dramatic voice with pieces like *The Dissolution of Dominick Boot* (1964), *M Is for Moon among Other Things* (1964), and *If You're Glad I'll Be Frank* (1965). In 1965, the BBC commissioned a longer radio drama from Stoppard that resulted in *Albert's Bridge* the following year. With a full hour to fill, Stoppard revealed his early willingness to entrust his play's narrative to mathematics, even if all the high school classics major knew at the time was a little basic algebra.

I. E. B + E. G. Q

The eponymous central character of *Albert's Bridge* is a newly minted university graduate with a chronic disinterest in the real world. Having majored in philosophy, the best Albert can imagine for himself is an entry-level position at a retail philosophy boutique. "Of course, a philosopher's clerk wouldn't get the really interesting work straight off," he muses. "It'll be a matter of filing the generalizations, tidying up paradoxes, laying out the premises before the boss gets in—that kind of thing." (61)[9]

In the meantime, Albert takes a temporary job painting the Clufton Bay Bridge alongside three other blue-collar types. The fact that there are four total painters working on the bridge is significant. The silver paint the city uses lasts precisely two years before it requires repainting, which is exactly the amount of time required for four men to complete the job. Thus, when the four painters finish up the last few steel girders at the end of the span, they return the next morning to the other side of the bridge and begin all over again. Oppressive to the other three, the Sisyphean task is pure solace to Albert, who sings while he wiggles his brush into corners he knows no one else will ever see. There is no doubt, then, that it is going to be Albert who volunteers for the lonely duty required in a money-saving plan being hatched in the city below at a special meeting of the Clufton Bay Bridge Sub-Committee.

Mr. Fitch is the "clipped, confident, rimlessly-eyeglassed" town accountant, obsessed with efficiency and possessed of just enough mathematical intuition to do a great deal of damage:

> FITCH: The cycle is not a fortuitous one. It is contrived by relating the area of the surfaces to be painted—call it A—to the rate of the painting—

B—and the durability of the paint—C. The resultant equation determines the variable factor X—i.e. the number of painters required to paint surface A at speed B within time C. For example—

CHAIRMAN: E.g.

FITCH: Quite. Er, e.g. with X plus one painters the work would proceed at a higher rate—i.e. B, plus, e.g. Q. (59)

In 1967, the only established way to talk about mathematics within a play was through farce, which this certainly is, but there is some logic driving Fitch's presentation. Fitch is proposing that the city switch from using the current brand of paint, which lasts two years, to a new brand of paint which lasts eight years. What is causing the confusion is that this new brand of paint is more expensive; in fact, it costs exactly four times as much as the current brand and thus on the surface of things, so to speak, it seems like a wash. Fitch's pseudo-math jargon manages to baffle everyone at the meeting, including Fitch, until the Chairman finally calls the question:

CHAIRMAN: Pull yourself together, Fitch—I don't know what you're drivillin' about.

GEORGE: In a nutshell, Fitch—the new paint costs four times as much and lasts four times as long. Where's the money saved?

FITCH: We sack three painters.

(*Pause.*)

CHAIRMAN: Ah . . . . (60)

If four men can paint the bridge in two years, then one can paint it in eight. The rigidity of the algebra of this eighth-grade word problem is accented by the steel beams of the bridge itself. The bridge, like the algebra, is functional, definitive, and unambiguous in its purpose. Albert, by contrast, is an amorphous soul. He unwittingly stumbles into a tryst with his mother's house cleaner and dutifully marries her when she gets pregnant. But a wife, a baby girl, and a job prospect at his father's firm are no match in Albert's mind for the allure of Fitch's unique brand of optimizing mathematics:

FITCH: I'm the same. It's poetry to me—a perfect equation of space, time and energy—

ALBERT: Yes—

FITCH: It's not just slapping paint on a girder—

ALBERT: No—

FITCH: It's continuity—control—mathematics.
ALBERT: Poetry.
FITCH: Yes, I should have known it was a job for a university man. . . . You'll stick to it for eight years will you?
ALBERT: Oh, I'll paint it more than once. (65)

The Bridge Man

Some of the most entertaining and thought-provoking moments in the play come when Albert is joined on the bridge by Fraser. Convivially neurotic, Fraser is convinced that society has exceeded its capacity to stay ordered and senses that the apocalypse is at hand. He makes a habit of climbing up the bridge with the intent of throwing himself off, but each time he does so the perspective of the city as a gently humming arrangement of dots and squares makes his anxieties go away. "Yes, from a vantage point like this, the idea of society is just about tenable." (78) Albert, meanwhile, is morphing into "the bridge man" who lords over the toy town below. Having his solipsistic daydreams routinely interrupted, Albert is annoyed rather than moved by Fraser's suicidal agenda. "Aren't you going to try to talk me out of it?" Fraser pleads to Albert. "You know your mind. And you're holding me up," is Albert's reply. "I've got to paint where you're standing." (78)

The laugh lines and barroom philosophy bantered about between Albert and Fraser are good fun, but the real hook for *Albert's Bridge* turns out to be the mathematics. What Stoppard instinctively knew, even at this early stage, was that the sure-footedness of mathematics was most potent when it was deployed to *undermine* common sense. At its artistic best, mathematics could be a tool for creating uncertainty. Although Fitch's algebra seems airtight, it becomes clear as the play progresses that there is a fatal oversight in his calculations. (As a challenge, take a moment to try to spot it before reading on.) Although the paint Albert is applying to the bridge lasts eight years, the paint he is covering up is only meant to last for two. Working on his own, Albert cannot keep up with the rate of decay. After two years, Albert is only a quarter of the way across the span, meaning that three-fourths of the bridge are now in various stages of unsightly disrepair. The Chairman of the Clufton Bay Bridge Sub-Committee is undone. Broken and in a panic, Fitch crafts a solution that holds up on paper but is anathema to Albert:

FITCH: I have made arrangements.
ALBERT: What arrangements?

FITCH: Eighteen-hundred painters will report for work at seven o'clock tomorrow morning. By nightfall the job will be done. I have personally worked it out, and my department has taken care of the logistics.

ALBERT: Eighteen-hundred?

FITCH: Seventeen-hundred and ninety-nine. I kept a place for you. I thought you'd like that. (82)

For what it's worth, Fitch's calculations are fairly reasonable. Working 300 days out of the year, it is going to take Albert roughly

$$(6 \text{ years}) \cdot (300 \text{ days/year}) = 1{,}800 \text{ days}$$

to completely refinish the old paint on his own. By compressing the totality of this labor into a single workday, Fitch sets the stage for the play's denouement, which includes one final nod to mathematics.

As the army of painters marches inexorably toward the bridge, Albert and Fraser each see an incarnation of their own worst nightmare. For Fraser, it is the chaos of society pushing outward and upward into his last place of refuge. For Albert, the painters are an angry mob coming to take the imperious bridge man away. Both end up being partially correct. Forgetting to break stride as they march onto the surface of the bridge, the resonating frequencies of the 1,800 collective footsteps bring the bridge, Fraser, Albert, and the play to a crashing end.

Albert's Bridge was completed in 1966. Greeted with modest approval after it ran several times on BBC radio, the play went on to enjoy an interesting afterlife. In 1968 it won an international prize awarded to plays for radio and was performed as a stage play a number of times. One memorable series of three performances was held in the girders of the Royal Exchange Theatre in Manchester. In 1969, Stoppard expanded *Albert's Bridge* into a full-length screenplay.[10] Although the film was never produced, Stoppard's collaborator on the project—a friend and writer named Anthony Smith—eventually adapted the original version of *Albert's Bridge* into an operetta which was performed in 1999.

Rosencrantz and Guildenstern Are Dead

Well, it was an even chance, if my calculations are correct.

—GUILDENSTERN, FROM
ROSENCRANTZ AND GUILDENSTERN ARE DEAD

At the same time that he was working on *Albert's Bridge* as well as his contracted novel, Stoppard returned to the *Hamlet* pastiche he had started in Berlin the year before. It would take several years and many drafts, but the end result would transform Stoppard's career. First performed at the Edinburgh Fringe Festival in August 1966, *Rosencrantz and Guildenstern Are Dead* vaulted Stoppard from struggling writer and journalist to the upper echelons of active playwrights. A half century and some fifty plays and screenplays later, *Rosencrantz and Guildenstern Are Dead*—or *R&G* for short—is still Stoppard's most iconic and identifiable piece of writing.

In Shakespeare's original play, Rosencrantz and Guildenstern are school friends of Hamlet who appear briefly in a number of scenes, always in tandem and with their respective identities somewhat conflated. They first arrive when Claudius summons them to court to tease out what is afflicting Hamlet, but their old friend has no trouble recognizing Rosencrantz and Guildenstern for the spies that they are. Later, Claudius gives Rosencrantz and Guildenstern the task of taking Hamlet to England where Hamlet is to be executed upon his arrival. Shakespeare arranges for Hamlet to escape at sea, but not before Hamlet has altered the contents of the sealed order so that it now requests that Rosencrantz and Guildenstern be the ones executed by the English king.

The title of Stoppard's 1964 Berlin sketch—*Rosencrantz and Guildenstern Meet King Lear*—reflects his original idea to explore what would happen if Lear were the king that Hamlet's two friends encountered when they arrived, without Hamlet, on English soil. Although the various plot possibilities ultimately proved unsatisfying, the characters of Rosencrantz and Guildenstern held Stoppard's interest. Rather than invent elaborate biographies for them, the interesting challenge was to explore who they would be if their lives consisted of no more than the scant bits of action that Shakespeare's script requires of them. Following this logic, Stoppard removed Lear from the story and shifted his attention back in time to when Rosencrantz and Guildenstern are at Elsinore. In fact, he followed them back in time to a moment just before Elsinore, before anything has happened to them—before any choices have been made or any memories have accrued. "Two Elizabethans passing

the time in a place without any visible character," is how the stage directions of this new account of Rosencrantz and Guildenstern begin. What might such a place be like? How could Stoppard make it nondescript yet different from any place we had ever been? What could the two be doing to pass the time? What could there be to talk about if nothing had happened yet?

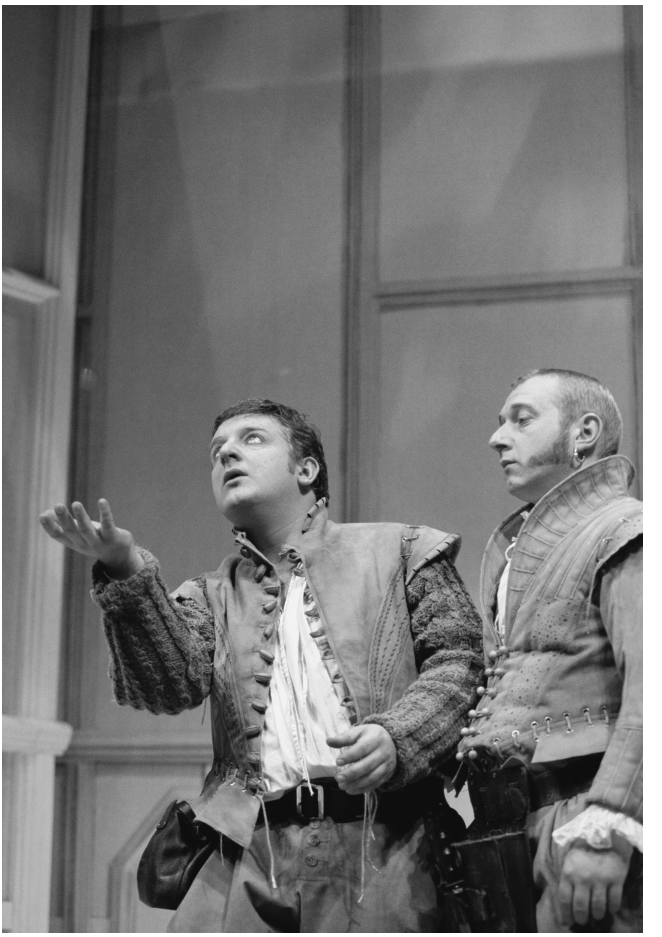
Stoppard solved all these problems with a single mathematical device.

A Multipurpose Coin

The curtain rises in *R&G* to find the two misplaced Elizabethans betting on the flip of a coin; heads and the coin goes to Rosencrantz, tails and it belongs to Guildenstern. It is immediately clear that something is amiss. Each flip we witness turns up heads, and Rosencrantz's heavy bag of coins indicates that this has been happening for quite some time. Rosencrantz is slightly embarrassed to be taking so much money from his friend but seems uninterested in considering the matter much further. Guildenstern couldn't care less about the money but is clearly disturbed by the implications.

> GUIL: It must be indicative of something, besides the redistribution of wealth. (*He muses.*) List of possible explanations. One: I am willing it. Inside where nothing shows, I am the essence of a man spinning double-headed coins, and betting against himself in private atonement for an unremembered past. (*He spins a coin at Ros.*)
>
> ROS: Heads.
>
> GUIL: Two: Time has stopped dead, and the single experience of one coin being spun has been repeated ninety times. (*He flips a coin and tosses it to Ros.*) On the whole doubtful. Three: divine intervention . . . Four: a spectacular vindication of the principle that each individual coin spun individually (*he spins one*) is as likely to come down heads as tails and therefore should cause no surprise each individual time it does. (*It does. He tosses it to Ros.*) (16)[11]

In between flips, Rosencrantz and Guildenstern scour their essentially nonexistent memories for scraps of information that might help them determine what they are about. Rosencrantz is the instinctive, emotional member of the pair—the tail, so to speak. Guildenstern is the more cerebral one. Conveniently, mathematics is universal, present in a world devoid of empirical experiences, and Guildenstern is enough of a mathematician to sense that a run of ninety heads is highly suspect in any conception of nature. He is also enough of a mathematician to instinctively know some Aristotelian logic, and



"It must be indicative of something, besides the redistribution of wealth." *Rosencrantz and Guildenstern Are Dead*; Simon Russell Beale (Guildenstern), Adrian Scarborough (Rosencrantz); National Theatre, 1995. © Donald Cooper/photostage.co.uk.

he begins organizing his arguments into the form of the logical syllogisms that Aristotle championed.

> GUIL: One, probability is a factor which operates within natural forces. Two, probability is not operating as a factor. Three, we are now within un–, sub– or supernatural forces. Discuss.

But the heady Guildenstern is not done yet. Moments later, he attempts to turn his own logic back on itself.

> GUIL: If we postulate, and we just have, that within un–, sub– or supernatural forces the probability is that the law of probability will not operate as a factor, then we must accept that the probability of the first part will not operate as a factor, in which case the law of probability will operate as a factor within un–, sub– or supernatural forces. And since it obviously hasn't been doing so, we can take it that we are not held within un–, sub– or supernatural forces after all; in all probability, that is. (17)

The coin has one other important function to fulfill. In addition to setting the existential tone in its refusal to obey the law of averages, it also points to the symbiotic relationship between Stoppard's script and the script of *Hamlet*. After muddling about on their own at the beginning of the play, Rosencrantz and Guildenstern encounter a ragged group of traveling actors on their way to Elsinore. These turn out to be the players that Hamlet recruits to perform for Claudius in order to "catch the conscience of the king." The Player is the shifty spokesperson for the troop, and he does his best to tempt Rosencrantz and Guildenstern with a private performance of their own choosing. "We do on stage the things that are supposed to happen off," he says suggestively, "which is a kind of integrity, if you look on every exit being an entrance somewhere else." (28) On cue, the coin does finally come up tails—at precisely the moment when Hamlet and Ophelia swoon on stage and the action is taken over by *Hamlet*, act II, scene 2.

Stoppard manages to sustain this complementary relationship between his play and Shakespeare's throughout the evening. It is as though there is a full production of *Hamlet* taking place just offstage. When they are required, Rosencrantz and Guildenstern are swept into the action. They earnestly recite their scant few lines and just as abruptly are left alone again to pass the time and ponder their predicament. The comic opportunities are substantial, but there is still the question of whether this arrangement can support the weight of a full-length play in three acts. Recounting the story of the original performance of *Rosencrantz and Guildenstern Are Dead*, Stoppard explained that, in point of fact, the whole production nearly collapsed before the curtain even went up.

Clean What Afflicts Him

The Edinburgh Fringe Festival is an open access showcase for the performing arts that has been running annually since 1947. It was spontaneously created as an offshoot of the established Edinburgh International Festival when a

handful of uninvited theater companies crashed the more formal festival, taking advantage of the large crowds who had gathered by performing in smaller venues around the "fringe" of the city. By 1966, the Fringe was more coordinated and growing quickly, but it still featured unvetted and innovative work performed in nontraditional venues. Eager to get *R&G* on its feet, Stoppard gladly consented to letting a reputable student group mount a production as part of the Fringe at the Cranston Street Hall. When Stoppard arrived to sit in on the last stretch of rehearsals, he encountered a show in disarray. Here is how Stoppard described what he found, in a program note he wrote fifteen years later:

> I had arrived in Edinburgh a few days previously to be shown the fruits of rehearsal. The Oxford Theatre Group had been laboring under certain disadvantages. The director had abandoned ship before we had left port. The actors were using scripts typed by somebody who knew somebody who could type. And the first thing that struck me was that there were a few unfamiliar cadences and some curious repetitions in the text they were using. . . . It turned out that such was the Oxford Theatre Group's touching faith in my play that they were faithfully rehearsing the typographical errors. The authentic Shakespearean phrase 'Glean what afflicts him' was coming out as 'Clean what afflicts him'. So we stopped and tidied all that up.[12]

One reason that Stoppard gives for remaining so sanguine throughout the chaos was that his novel, *Lord Malquist and Mr. Moon*, was due out from the publisher in the same week that *R&G* was to open. As odd as it sounds to say it now, Stoppard was confidently banking on the book to establish his writing credentials with the larger public.

Reports of the size of the opening night audience of *Rosencrantz and Guildenstern Are Dead*, which occurred on Wednesday, August 24, 1966, range from a handful to a couple of dozen. Stoppard recalls their response was more affable than awed. The following Sunday, when he boarded his train back to London carrying a copy of the *Observer* under his arm, Stoppard still had no idea his life as a playwright was about to radically change. A number of the local reviewers who reported on the show were skeptical about whether *R&G* was much more than a clever sketch that had gone on for too long, but an influential critic named Robert Bryden who knew something of Stoppard's BBC work had been among the sparse early audiences and recognized the full potential

of both the play and its author. "Behind the fantastic comedy," Bryden wrote in his review,

> you feel allegoric purposes move: is this our relation to our century, to the idea of death, to war? But while the tragedy unfurls in this comic looking-glass, you're too busy with its stream of ironic invention, metaphysical jokes and linguistic acrobatics to pursue them. Like *Love's Labour's Lost* this is erudite comedy, punning, far-fetched, leaping from depth to dizziness. It's the most brilliant debut by a young playwright since John Arden.[13]

The last line in the review was also the headline in the *Observer* that Stoppard saw next to his picture when he finally opened the paper on the train. When he arrived back in London he was greeted by a telegram from Kenneth Tynan at the National Theatre inquiring about the play.

A polished production of *Rosencrantz and Guildenstern Are Dead* played to sold-out houses at the National Theatre starting in April 1967. It opened on Broadway in October 1967, where it earned a sizable haul of commendations, and soon after, translated versions started appearing across the major cities of Europe.

Newton's Apple or Eve's?

While *R&G* effectively launched Stoppard's career, it is overstating matters to say it represents a popular breakthrough for mathematics on stage. The nods to mathematics in *R&G* are modest and safely ensconced in the bantering word play. Guildenstern has a mathematician's sensibilities, leaning on his analytical skills to make sense of the world he inhabits. Rosencrantz, meanwhile, is the empirical philosopher, content to draw his conclusions from his experiences, however scant those may be.

Much of the comedy in *R&G* stems from the classical arrangement of having the audience know more than the actors on stage. Our knowledge of the plot of *Hamlet* gives us a vantage point from which to enjoy Rosencrantz and Guildenstern's metaphysical struggles without feeling any threat to our own existential security. But for *R&G* to work as allegory—to borrow Bryden's word—that security needs to be eroded. *R&G*'s darker overtones become more audible as Stoppard aligns Rosencrantz and Guildenstern's situation with our own by granting them just enough freedom to wonder at their predicament but not enough to see it for what it is. "Intrigued without ever quite being enlightened," is how Guildenstern summarizes it. (41) The script of *Hamlet* that spawned the two Shakespearean extras looms omnipotently

"Intrigued without ever quite being enlightened." *Rosencrantz and Guildenstern Are Dead*; Simon Russell Beale (Guildenstern), Adrian Scarborough (Rosencrantz), Paul Rattigan (Hamlet), Claudie Blakley (Ophelia); National Theatre, 1995. © Donald Cooper/photostage.co.uk.

over their hollow lives, but in their copious offstage time Stoppard manages to turn Rosencrantz and Guildenstern into flesh and blood seekers of truth whose fears and uncertainties sound more and more familiar as the evening wears on.

The major contribution of mathematics to establishing this uncertainty is in the mischievous coins from the opening scene, but when he was offered the chance to adapt *R&G* into a screenplay, Stoppard saw that there were more untapped dramatic possibilities lying in wait at the scientific end of the intellectual spectrum. In the film, which Stoppard wrote and directed, Rosencrantz's empirical disposition brings him face to face with a number of the laws that govern the physical world. En route to his predestined demise, the cinematic version of Rosencrantz almost manages to discover Galileo's principle of falling objects, Newton's principle of the conservation of momentum, and Archimedes's law of floating bodies. With each of these encounters, the film draws attention to the natural forces at play in the universe, implicitly asking whether the future is controlled by providence or probability. With each fumble by Rosencrantz, the answer gets more obscure. When an apple falls on Rosencrantz's head, he has a fleeting vision of the law of universal gravitation,

an idea that will one day usher Western civilization into the Enlightenment. He stares at the apple:

ROS: I say . . .
GUIL: What?
ROS: Well . . .[14]

But no. Rosencrantz abandons the thought and instead takes a bite out of his apple. In the blink of an eye, we have gone from Newton under the tree to Adam in the garden, whimsically illustrating the tug-of-war between science and religion as competing systems for making sense of the human condition.

A Play-within-Itself

The extensive critical attention directed at Stoppard's work has produced an array of fascinating interpretations of *R&G* as an existential, allegorical, absurd, and even postmodern play. Endorsing this diversity of opinion, Stoppard scholar and theater historian John Fleming compares *R&G* to Shakespeare for the way that "critics often find what they bring to it; their own values are reflected back." Eschewing labels, Fleming celebrates *R&G* as "contradictory and expansive, [a play] that raises as many questions as it offers tentative answers."[15] An innovative way that Stoppard's play achieves this universal sense of relevance is by harnessing the full potential of the gift Shakespeare bequeathed with the traveling players' production of the *Murder of Gonzago*. Although not so obvious, there is a mathematical aspect to this particular component of *R&G* which is central to the play's "contradictory and expansive" aura.

The way it is arranged in Shakespeare's play, Hamlet requests some edits to *Gonzago* that essentially transform it into a portrayal of Claudius's murder of Hamlet's father. Not content with the single scene Shakespeare provided, Stoppard has Rosencrantz and Guildenstern stumble onto a dress rehearsal of the troupe's *Gonzago* which Stoppard extends into a full rendition of the story of *Hamlet*. Among other things, this leads to the provocative moment of Rosencrantz and Guildenstern unknowingly witnessing a portrayal of their own executions at the hands of the English king.

In the history of mathematics, the reflexive arrangement of having some object (e.g., a set, a function, a logical sentence) contain or refer to itself has led to powerful new constructions and as many controversies. *R&G* represents

an intriguing artistic translation of this phenomenon. While the play-within-a-play device is a familiar theatrical trope, the more distinctive play-within-*itself* structure that *R&G* inherits from *Hamlet* is what enables Stoppard's play to toggle back and forth between a music hall slapstick and an exegesis on the human condition. For his part, Stoppard is adamant that he was intent on writing a comedy.[16] Taking the playwright at his word, it is still evident that the logically attuned Stoppard was enticed by the introspective overtones that emerged as he moved the focus of his story from England back to Elsinore where the Player and his tragedians resided. By the time he makes *R&G* into a movie, Stoppard is acutely aware of the paradoxical echoes that result from embedding a copy of a play inside the original. To highlight this in the film version, Stoppard adds in a puppet show of *Gonzago* as part of the troupe's rendition of *Hamlet* happening within Stoppard's *R&G* which is conjoined with Shakespeare's *Hamlet*. All of this is, of course, taking place in front of an audience, who, judging from the fact that Rosencrantz and Guildenstern are caught unaware in this strange loop, should not assume that the recursive levels end with the theater in which they sit.

Jumpers

> If rationality were the criterion for things being allowed to exist, the world would be one gigantic field of soya beans!
>
> —GEORGE, FROM *JUMPERS*

The mathematics in *R&G* is significant but subtle, largely appearing in disguise in the form of statistical anomalies and Guildenstern's Lewis Carroll-like musings. On this same point, most audience members would not associate the self-referencing structure of *R&G* with being explicitly mathematical. Stoppard probably didn't either. The mathematics in *R&G* is not so much a conscious artistic decision as it is a by-product of Stoppard's logical instincts. In terms of mathematics, logical instincts and some algebra were all the high school–educated playwright had to go on at this early point in his career, but this was about to change. In 1968, Stoppard wrote to a friend about his ongoing self-education:

> I'm on a ridiculous philosophy/logic/maths kick. I don't know how I got into it, but you should see me trying to work out integral calculus

> with one hand, while following Wittgenstein through 'Tractatus Logico-philosophicus' with the other. I shall end up writing an unsatisfactory play by preparing just enough ground to reveal the virgin and impenetrable tract(atus).[17]

As Stoppard progressed further into the intellectual weeds, an opportunity appeared for bringing mathematical insights to bear on human ones, albeit in a backhanded way. Ludwig Wittgenstein is a prime example of a philosopher who attempted to export the tools of formal logic from the mathematical realm, where they had proved inordinately effective, to other fields of inquiry. Stoppard, like Wittgenstein, became fixated on the tension between the clarity that a strictly logical approach to knowledge offers in the abstract and the largely unsatisfying results it yields when applied to issues like language and morality. This is the fulcrum on which Stoppard perched *Jumpers*. His next full-length play after *R&G*, *Jumpers* opened in February 1972 at the National Theatre in London to great fanfare. It is a philosophy play, not a math play; there is more Wittgenstein in the script than there is integral calculus. Logical reasoning, however, is a significant motif, and the roots of calculus in the form of Zeno's paradoxes play a pivotal role.

The title of *Jumpers* refers to its acrobats. As Stoppard was piecing together the intellectual arguments of the play, he had a vision of a large human pyramid. In his imagination, one of the acrobats on the bottom row gets shot, bringing the whole structure tumbling down. "I had this piece of paper with this dead acrobat on the floor and I didn't know who he was, who shot him or why."[18] In search of a metaphor for his collapsing pyramid, Stoppard combined his skepticism of higher education with his newfound infatuation with philosophy. The result, many drafts later, was an elaborate staging of a philosophical disputation in which mathematics is invoked in support of a position one might not anticipate: the existence of God.

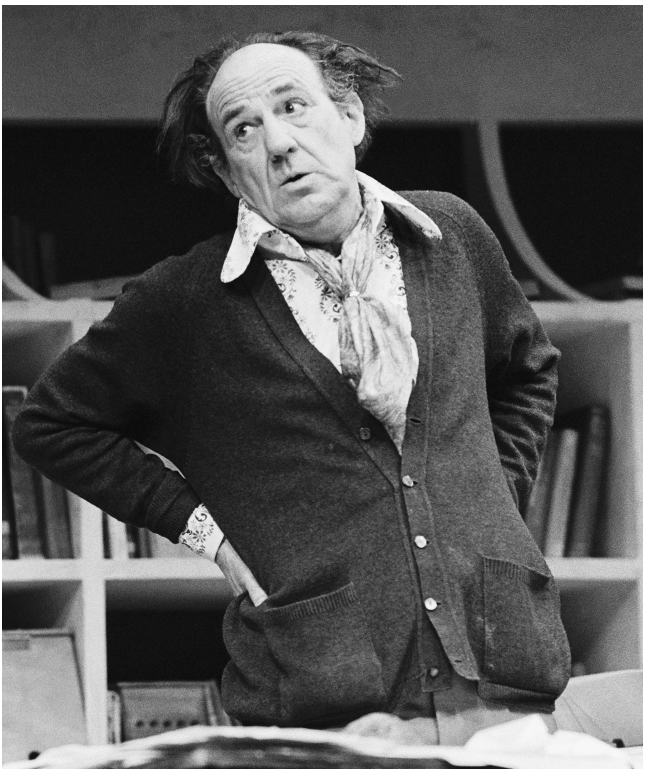
Mental Gymnastics

Jumpers is centered, literally and figuratively, around an academic debate. In one corner is George Moore, professor of moral philosophy. Throughout the play, George has a number of extended monologues during which he dictates a speech he is scheduled to deliver at an upcoming symposium titled "Man: Good, Bad, or Indifferent." The central topic of the debate is the question of the existence of moral absolutes, with George taking the affirmative. This antiquated position puts George squarely at odds with the

prevailing empiricist movement, which requires that statements be experimentally verifiable to be meaningful. George's adversary, and overall nemesis, is the university vice-chancellor Sir Archibald ("Archie") Jumper.[19] For Archie and his followers, the moral code that undergirds a functioning society does not originate from a benevolent creator, nor does it enjoy any privileged universal status. Instead, notions of ethical behavior are the result of practical norms and therefore subject to change. Assessing this point of view with equal parts contempt and fascination, George summarizes his adversaries's position by saying that in their minds "good and bad aren't actually *good* and *bad* in any absolute or metaphysical sense, . . . [they are] categories of our own making, social and psychological conventions which we have evolved in order to make living in groups a practical possibility, in much the same way as we have evolved the rules of tennis without which Wimbledon Fortnight would be a complete shambles." George concedes that empiricists like Archie are not advocating that murder and lying become commonplace, as anarchy would likely ensue, but it does allow them "to conclude that telling lies is not *sinful* but simply anti-social." (48)[20]

To turn this philosophical debate into a play, Stoppard surrounds George with an array of ethically ambiguous scenarios. The curtain rises on a raucous party taking place in George and Dotty's apartment. The celebration is for the recent victory of the Radical Liberal party, a political incarnation of the morally relativistic tenants of Archie's logical positivist worldview. Archie is the party's MC, Dotty its songstress, but the main attraction of the evening is a performance by the "INCREDIBLE—RADICAL!—LIBERAL!!—JUMPERS!!" Consisting generally of the members of the philosophy department (without George, of course), the Jumpers' show ends tragically when an unseen gunshot takes out Duncan McFee, professor of logic and the colleague George is scheduled to debate at the upcoming symposium. By morning, Dotty has concealed the body by hanging it on the back of her bedroom door. She may or may not have fired the shot. She also may or may not be having an affair with Archie who, in addition to being vice-chancellor and gym coach, is also a coroner, lawyer, and Dotty's psychiatrist.

> GEORGE: (*reckless, committed*) I can put two and two together, you know. Putting two and two together is my *subject*. I do not leap to hasty conclusions. I do not deal in suspicion and wild surmise . . . Now let us see. What can we make of it all? Wife in bed, daily visits by gentleman caller. Does anything suggest itself?
>
> DOTTY: (*calmly*) Sounds to me he's the doctor. (32)



"Somewhere there is a domino which was *nudged*." *Jumpers*; Michael Hordern (George); Old Vic Theatre, 1972. © Donald Cooper/photostage.co.uk.

This exchange illustrates the central asset that theater brings to a debate about whether knowledge should be restricted to what can be empirically confirmed. Over and over again in *Jumpers*, Stoppard allows his audience to experience firsthand how the same collection of observations can be explained by a variety of different realities. A compelling anecdote recounted in the play makes clear how fundamental this phenomenon is in any clear-minded pursuit of truth:

GEORGE: (*facing away, out front, emotionless*) Meeting a friend in a corridor, Wittgenstein said: 'Tell me, why do people always say it was *natural* for men to assume that the sun went round the earth rather than the earth was rotating?' His friend said, 'Well, obviously, because it just *looks* as if the sun is going around the earth.' To which the philosopher replied,

'Well, what would it have looked like if it had looked as if the earth was rotating?' (75)[21]

Saint Sebastian Died of Fright

Stoppard's budding interest in higher mathematics enters the play through George's long monologues in which he dictates his symposium lecture to his secretary. George has an ambitious agenda, and Stoppard does too. George's intention is to establish a universal moral compass by arguing for the existence of a benevolent God; Stoppard's job is to find the right balance between philosophy and farce so that the academic lecture does not actually feel like one but the play doesn't collapse into frivolity.

Postponing his argument for benevolence, George's initial goal is to make the case for the existence of some kind of cosmic deity in general. "Does, for the sake of argument, God, so to speak, exist? . . ."

GEORGE: We see that a supernatural or divine origin is the logical consequence of the assumption that one thing leads to another, and that this series must have had a first term; that, if you like, though chickens and eggs may alternate back through the millennia, ultimately, we arrive at something which, while perhaps no longer resembling either a chicken or an egg, is nevertheless the first term of that series and can itself only be attributed to a First Cause—or to give it its theological soubriquet, God. (27)

This line of reasoning puts George on sound theological ground alongside St. Thomas Aquinas, who in George's words argued for the existence of God based on "the simple idea that if an apparently endless line of dominoes is knocking itself over one by one then somewhere there is a domino which was *nudged*." (29) In anticipation of counter arguments, George brings mathematics more explicitly into the story by invoking its extensive experience negotiating with the infinite.

GEORGE: Mathematicians are quick to point out that they are familiar with many series which have no first term—such as the series of proper fractions between naught and one. What, they ask is the first, that is the smallest, of these fractions? A billionth? A trillionth? Obviously not: Cantor's proof that there is no greatest number ensures that there is no smallest fraction. There is no beginning. (27)

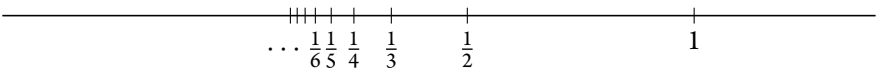


FIGURE 1.1. A sequence with no beginning.

The name George drops here is that of Georg Cantor, a late nineteenth-century mathematician whose contributions to the understanding of the infinite were nothing short of revolutionary. Cantor's ideas will garner their share of attention in discussions to come, but with all due respect to George, Cantor is not really required here. Long before Cantor, it was a commonly understood notion that the set of natural numbers—1, 2, 3, 4, 5, 6, . . .—has no largest element and increases without bound. This is all one needs to prove that the sequence of proper fractions

$$1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \ldots$$

decreases indefinitely with no candidate for a smallest one. Looking at it from left to right along the number line (Figure 1.1), the collection of proper fractions has no beginning; and so, the logic goes, maybe the universe of falling dominos does not either.

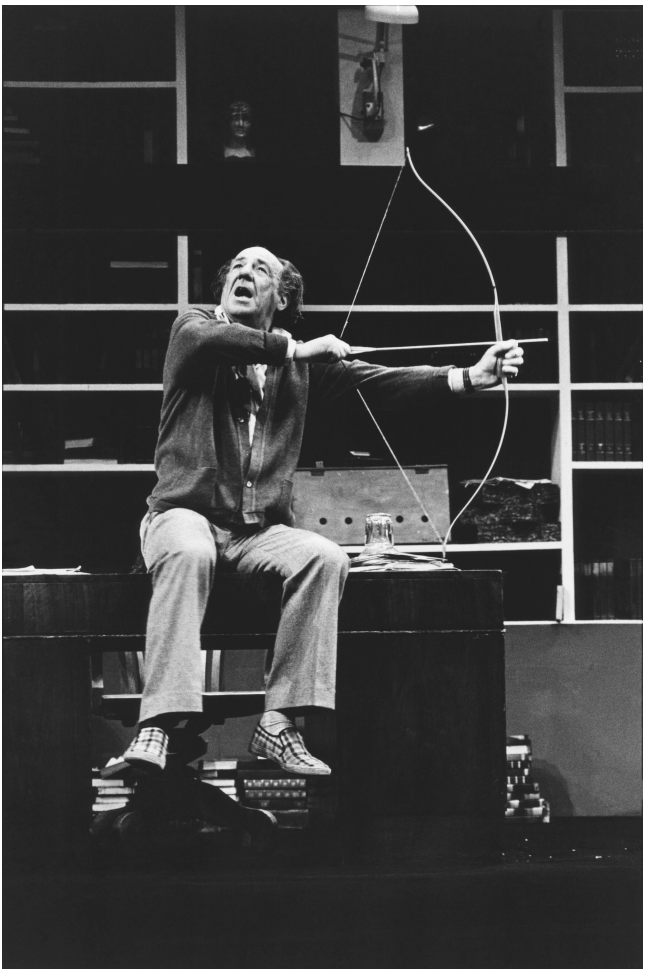
Does this example deal a fatal blow to George's argument for God as First Cause? Not necessarily! George is prepared to defend himself—with props, no less. Continuing his dictation, George provocatively produces a quiver of arrows and a bow, and deftly notches an arrow in the string:

> GEORGE: But it was precisely this notion of infinite series which in the sixth century BC led the Greek philosopher Zeno to conclude that since an arrow shot towards a target first had to cover half the distance, and then half the remainder, and then half the remainder after that, and so on *ad infinitum*, the result was, as I will now demonstrate, that though an arrow is always approaching its target, it never quite gets there, and Saint Sebastian died of fright. (28)

With the bow taut, George is suddenly startled by his wife's cry for help and proceeds to fire the arrow over the wardrobe in his study.

Zeno of Elea

Historical knowledge of Zeno is scant. He appears in one of Plato's dialogues as a student and defender of Parmenides, which is essentially how Zeno has come to be viewed. Parmenides was a philosopher who argued



"And Saint Sebastian died of fright." *Jumpers*; Michael Hordern (George); National Theatre, London, 1976. © Donald Cooper/photostage.co.uk.

for the unorthodox idea that all of reality consisted of a single changeless unity. This position is significantly at odds with the plurality of distinct things that common observation would naturally suggest. In defense of Parmenides, Zeno reportedly wrote a book of paradoxes designed to discredit the senses by demonstrating logical contradictions that arise from sensory observation such as physical motion. The book did not survive, but references to a handful of these paradoxes appear in later texts, most notably in Aristotle's *Physics*.

Keeping in mind that everything we know about Zeno is secondhand, Stoppard, through the character of George, is participating in what is a long

tradition of adapting Zeno to his particular purpose. That said, some moderate tidying up of the details is probably in order. One of Zeno's paradoxes is indeed about an arrow, but it says something a bit different. Zeno argues that at a fixed instant in time, a flying arrow occupies an amount of space exactly equal to its shape and size. In other words, the arrow is not moving. Stepping back and noting that any interval of time is composed of a collection of such instances, it follows that at no time is the arrow in motion and thus it cannot in actuality progress from the bow to its target.

Another of Zeno's paradoxes argues for the impossibility of motion along the lines that George describes.[22] George's conflation of these two paradoxes causes no real harm, but it is worth noting that Zeno is being more thorough than George gives him credit for by considering the problem of infinite divisibility of both space and time. Is a line segment a collection of points? Is a time interval a collection of instances? In either case, Zeno points to a logical contradiction that arises from uncritically accepting the evidence of our eyes.

In citing Zeno, George's agenda is different from the one Zeno originally intended. Zeno attempted a radical attack on empiricism, an agenda to which George is generally sympathetic. But at the moment, George is laden with proving the existence of God, and standing in the way of his First Cause argument is his unease with Zeno's infinities. George's other problem is the chaos taking place in his apartment that routinely scrambles his already addled train of thought. "Everything has got to begin somewhere," he dictates to his secretary over the hum of the political celebration going on outside,

> and there is no answer to *that*. Except, of course, why does it? Why, since we accept the notion of infinity without end, should we not accept the logically identical notion of infinity without beginning? My old— Consider the series of proper fractions. Etcetera. (*To Secretary.*) Then Cantor, then no beginning, etcetera, then Zeno. Insert: But the fact is, the first term of the series is not an infinite fraction but *zero*. It exists. God, so to speak, is nought. Interesting. Continue. (29)

Aha! God is zero, if only George can get there along his sequence of decreasing fractions. Thus, all George has to do is show that Zeno erred and that it *is* possible to complete an infinite number of tasks in a finite amount of time. Putting his own particular dramatic spin on another of Zeno's paradoxes, George pulls out two small animal cages, explaining that, just as Zeno had argued that the arrow could never reach its target, he similarly asserted that a "tortoise given a head start in a race with, say, a hare, could never be overtaken." (29)

The tortoise and the hare are borrowed from the race in Aesop's famous fable. In Zeno's formulation it is Achilles, the fleetest of all mortals, who gives a head start to the tortoise. The reason Achilles cannot overtake the tortoise, Zeno says, is because each time Achilles reaches the place where the tortoise was, the tortoise has meanwhile moved ahead ever so slightly, and this process repeats itself ad infinitum. Substituting a rabbit for Achilles makes the point just as well—better in fact, because once again George is going to reveal the fallacy of Zeno's argument with a live demonstration. But just as his archery demo went awry, this one does too. Sadly for philosophy, Thumper the hare has escaped from his cage and is nowhere to be found.

More than Meets the Microscope

Throughout the play, the jokes and the philosophy swirl around the mystery of who killed Professor Duncan McFee. Dottie is a suspect, as is Archie, especially when it is revealed that McFee planned to resign his position as professor of logic and join a monastery. Even George's secretary, who never speaks, is dragged into the zone of suspicion as McFee's disgruntled mistress. Stoppard does not provide a definitive answer, which is wholly appropriate. Rather than a whodunit, *Jumpers* is an exploration of the limits of rational certainty in human affairs, and mathematics is invoked as a point of contrast to George's persistent befuddlement, often with language itself.

> GEORGE: Do I say 'My friend the late Bertrand Russell' or 'My late friend Bertrand Russell'? They both sound funny.
> DOTTY: Probably because he wasn't your friend.

While Russell does not appear, Stoppard contrives events so that this iconic mathematician's spirit is hovering just offstage.[23] The three large volumes of *Principia Mathematica* that Russell cowrote in an attempt to perfect the language of mathematical certainty cast a daunting shadow on George's struggle with his own language's imprecision with words like "good" and "bad." After two acts of trying to logically infer a benevolent God from self-evident principles while murders, infidelity, and self-interest encroach from all sides, George the moral philosopher abandons reasoned debate. "All I know is that I think that I know that I know that nothing can be created out of nothing," George confesses in desperation, "that my moral conscience is different from the rules of my tribe, and that there is more in me than meets the microscope." (68)

George's instinctive faith in an altruistic universe comes off as the more sympathetic alternative to Archie's overzealous rationalism, but even if it

(continued...)

INDEX

absurd, 36, 89, 117, 180, 210
Ackerley, Chris, 177, 181
Ada and the Engine (Gunderson), 13
Aeschylus, 5, 8, 342
After Darwin (Wertenbaker), 13
After Magritte (Stoppard), 247
Akousmatic, 138, 142
Alan Turing: The Enigma (Hodges), 286
Albert's Bridge (Stoppard), 21, 24–28, 71
algebra, 37, 170
  abstract, 132
  in Beckett, 133, 142
  in Jarry, 97
  in Stoppard, 16, 22, 25–27, 63–65, 71
Along the Cliffs of the Absurd (Witkiewicz), 113
altruism, 45, 272
And Our Faces, My Heart, Brief as Photos (Berger), 364
apple, 121
  Newton's, 35, 50
  Thomasina's, 20, 65, 68, 69
  Turing's, 313, 315, 327
  wicked queen's, 291, 317
Aquinas, St. Thomas, 41
Arcadia (Stoppard), 3, 12, 16–21, 61–72, 202, 235, 279, 281, 283, 287, 304, 337, 343, 345
Archimedes, 5, 8, 35, 342
  law of floating bodies, 95
Arden, John, 34
Aristophanes, 91, 237, 351, 359
Aristotle, 6–8, 31, 43, 77, 126, 127, 352
Artaud, Antonin, 97
artificial intelligence, *see* intelligence, machine
Artist Descending a Staircase (Stoppard), 249–251, 278
Auburn, David, 11, 13
  biography of, 336
  on origins of *Proof*, 337
Augustine, Saint, 353
avant-garde theater, 8, 12, 79, 87, 104, 186, 356
axiomatic systems, 10, 133, 168, 169, 176
  for hyperbolic geometry, 108, 117
  for set theory, 357
  for spherical geometry, 122
  for theater, 126
  in PA, 238
  in PM, 160, 175
  of Euclid, 81–87
axioms, 46, 48, 73, 74, 105, 133
  in formal systems, 171
  in PA, 241
Ayer, A. J., 352

Bair, Deirdre, 178
Basic Laws of Arithmetic (Frege), 156
Beautiful Mind, A (Nassar), 338
Beckett, Samuel, 9–12, 24, 186, 233, 343
  and consciousness, 184
  and identity, 12, 132, 133, 154
  and language, 12, 134, 138, 139, 144, 145, 146, 151, 168, 181, 183, 185
  and logic, 134, 177

Beckett, Samuel (*continued*)
Axel Kaun letter, 144–145, 167, 168
biography of, 135–136, 141
directorial control, 146
move toward abstraction, 178
Nobel Prize, 129
on *Finnegans Wake*, 136
on *Not I*, 164
on *Watt*, 142
patterning, 179
permutations, 180
scholarship of, 13, 168, 177, 180, 186
with Duthuit, 167
Berger, John, 364
Berkeley, Bishop, 150, 160
Birds, The (Aristophanes), 351
Birthday Party, The (Pinter), 368
Blakemore, Michael, 216
on *Copenhagen*, 217
Bletchley Park, 285, 287, 290–292, 305, 326
Bohr, Margrethe, 203
Bohr, Niels, 202
biography of, 205–206
science of, 206, 213, 214
Bolyai, János, 107–108, 111, 117, 121, 177, 343
Bolyai, Wolfgang, 107
Brazil (Stoppard), 48
Breaking the Code (Whitemore), 11, 286–294, 304–309, 312–314, 317, 328, 330
film version, 305
Brecht, Bertolt, 11, 12, 186–188, 202, 287
on *Life of Galileo*, 190
theory of drama, 189
Broadway, 34, 189, 216, 265, 336, 360
Brown, Gordon, 335
Bryden, Robert, 33, 34
builders language game, *see* Wittgenstein, Ludwig
butterfly effect, 63, 64, 71, 354
Byron, Lord, 62, 64
Calculus (Djerassi), 11
calculus, 11, 37, 38, 71, 102, 113, 316, 352
Cambridge, 2, 16, 18, 205, 219, 220, 223, 225, 228, 230, 232, 234, 255, 279, 282, 286, 288, 290–292, 319, 352
Cantor's Theorem, 11, 101
Cantor, Georg, 42, 44, 101, 103, 104, 125, 313, 343, 362
Carroll, Lewis, 37
Chalmers, David, 272, 368
Chaos: Making a New Science (Gleick), 63
chaos theory, 15, 20, 63, 65, 69–71, 73, 343
Chaplin, Charlie, 136, 161
Chekhov, Anton, 113
chess
analogy for formal systems, 170, 172, 239, 241
and Turing, 293, 321
in *Endgame*, 147, 150
in *Hapgood*, 55
match in *Murphy*, 139–140
Christie, Agatha, 245
Church, Alonzo, 291
Churchill, Caryl, 13
Clarke, Joan, 292, 318
Codron, Michael, 60
cognitive science, 237, 272, 275, 333, 367, 368
combinatorics, 133, 155, 178, 229
in *Quad*, 131, 132, 358
in *Watt*, 142, 143
Come and Go (Beckett), 178
complementarity, 203
Completeness (Moses), 11
completeness, 294, *see also* incompleteness
in Hilbert's program, 176
of PM, 174–176
Complicité, 2, 219, 220, 223, 232, 234
methodology of, 226–228, 231–232
"On Computable Numbers with an Application to the Entscheidungsproblem" (Turing), 291, 294, 300, 309
computer science, 285, 304, 369

"Computing Machinery and Intelligence" (Turing), 320–325, 367
consciousness, 12, 60, 237, 272, 276, 277, 325, 344
  Beckett's conception of, 181
  in *Not I*, 164
  in *The Hard Problem*, 274
  in *Watt*, 142
consistency, 134
  in relation to Beckett, 183
  of abstract theater, 126
  of axiomatic systems, 117, 183
  of PA, 263
  of PM, 174–176, 184, 236, 363
continuity, 229, 230
Copenhagen (Frayn), 202–206, 208–219, 287, 337
  film version, 205
Copenhagen Interpretation, 214, 215
Copernican revolution, 104, 187
Cracow Mathematical Society, 103
Crazy Locomotive, The: A Play without a Thesis in Two Acts and An Epilogue (Witkiewicz), 100
cricket, 23, 135, 220, 267–270, 341
Crookes, William, 97

Dada, 89, 249, 250
dance, 69, 72, 226, 230, 332
Dante, 132
"Dante . . . Bruno.Vico . . Joyce" (Beckett), 136
Davis, Hallie Flanagan, 202
De Cari, Gioia, 13
death, 34, 95, 120, 123, 228, 250, 252, 313, 315
Dechevaux-Dumesnil, Suzanne, 141
Delaney, Paul, 353
Demastes, William, 70
description number (of a Turing machine), 303
determinism, 63, 72
  Newtonian, 67, 69, 71, 208, 214
dimension, 100, 148, 194, 356
  fourth, 196
  sixth, 113, 119
Diophantus of Alexandria, 18
Dirty Linen (Stoppard), 48
Disappearing Number, A (Complicité), 1–3, 5, 9, 11, 219–234, 345
Dissolution of Dominick Boot, The (Stoppard), 25
Dogg's Hamlet (Stoppard), 253–256, 261
Doll's House, A (Ibsen), 78
double-slit experiment, 50–55, 206
downward causal power, 276
Dreams of Fair to Middling Women (Beckett), 136
Duchamp, Marcel, 250
Dürr, Hans-Peter, 218
Dürrenmatt, Friedrich, 11, 12, 202, 204, 210, 343
  biography of, 188
  theory of drama, 190–192
Duthuit, Georges, 167, 177

$E = mc^2$ (Davis), 202
Edinburgh Fringe Festival, 29, 32–33
Einstein, Albert, 8, 104, 113, 115, 118, 189, 201, 211, 291, 295
Elements (Euclid), 6, 8, 9, 13, 20, 73–77, 79–87, 104, 169
Eleutheria (Beckett), 153
Émilie du Châtelet (Gunderson), 13
empathy, 306–308, 312, 330
Empire of the Sun (Stoppard), 48
Endgame (Beckett), 146–153, 160, 162, 166, 178, 182, 186, 343
Enlightenment thinking, 36, 62, 64, 71
entropy, 20, 69
Entscheidungsproblem, *see* Hilbert's decision problem
epic theater, 189
Epimenides, 159
Epimenides paradox, 159, 160, 163, 167, 236, 244
esse est percipi, 150, 160, 219

Esslin, Martin, 358, 360
Euclid, 6–8, 62, 74, 76, 80, 81, 85, 108, 169, 177, 359
Euclid Freed of All Blemish (Saccheri), 105
Euclid's fifth postulate, 13, 74–77, 79, 80, 84, 85, 100, 105–112, 115, 117
Euclidean geometry, 6–7, 47, 48, 63, 73–77, 80–87, *see also Elements*
Euler, Leonard, 19, 56, 176, 361
Every Good Boy Deserves Favour (Stoppard), 46, 48
exotic concepts, 158–159, 245
Experiment with an Airpump, An (Stevenson), 13
Exploits and Opinions of Doctor Faustroll, Pataphysician (Jarry), 93

Fermat's Last Tango (Lessner and Rossenblum), 11
Fermat's Last Theorem, 11, 16–20, 22, 61, 62, 173, 310, 338
Fermat, Pierre de, 18, 19, 62
Feynman, Richard, 50, 51, 59
Fibonacci numbers, 259
Film (Beckett), 160–163, 165, 166
Finnegans Wake (Joyce), 136
Five Hysterical Girls Theorem, The (Groff), 11, 351
Fleming, John, 36
Footfalls (Beckett), 179, 180
Ford, John, 266
formal logic, *see* logic, formal
formal systems, 12, 170, 184, 236, 238, 242, 247, 268, 275, 278, 282, 290, 294, 329
"On Formally Undecidable Propositions of *Principia Mathematica* and Related Systems" (Gödel), 168
Foundations of Arithmetic, The (Frege), 157
fractal geometry, 20, 63, 65–67, 69, 72
Frayn, Michael, 11, 12, 202, 218, 230, 343
  biography of, 205
  on playwriting, 233
  on *Copenhagen*'s origins, 217
Frege, Gottlob, 12, 101, 134, 135, 160, 162, 163, 173, 177, 182, 184, 236, 360
  construction of natural numbers, 156–159
  on concepts and objects, 157, 245
  views on mathematical realism, 157
Frogs, The (Aristophanes), 359
"For Future Reference" (Beckett), 135

Galileo, 4, 35, 65
  in Brecht, 187–188, 190–191, 287
Gauss, Carl Friedrich, 112, 117, 125, 225
geometry, *see* Greek geometry, non-Euclidean geometry, hyperbolic geometry, spherical geometry, *Elements*
Gerould, Daniel, 100, 117, 356–358
Gleick, James, 63
God, 317
  Beckett's views of, 152
  in *Hapgood*, 46
  in *Arcadia*, 63
  in *Endgame*, 152
  in *Jumpers*, 38–45
  Jarry's views of, 97, 98
  Stoppard's views of, 352
  Turing's views of, 323
Gödel's Incompleteness Theorem, 12, 13, 134, 168, 177, 235, 237, 243–244, 262, 274–277, 282, 294, 304, 363, 367
  proof of, 183–184, 257–263
Gödel, Kurt, 4, 168, 176, 177, 235–237, 243–244, 255–263, 270, 272–278, 313, 367, 368
Gödel, Escher, Bach (Hofstadter), 367
Gödel-numbering, 257–260, 262, 302–303, 365
Goldbach's conjecture, 361
Gould, Victoria, 226, 228, 351, 364
Gowers, Tim, 232
Graham-Cumming, John, 334
graph theory, 56, 57, 132

Greek
faith in reason, 6
geometry, *see* Euclidean geometry, *Elements*
mathematics, 5–8, 20, 137, 167
philosophy, 6, 8, 42, 80, 137, 286
theater, 5–8, 189
Groff, Rinne, 11, 351
gross indecency, 281, 285
Gunderson, Lauren, 13
Gussow, Mel, 264, 265, 352, 354
Gyubal Wahazar: A Non-Euclidean Drama in Four Acts (Witkiewicz), 100, 113–118, 236

Half Life (Mighton), 331–334
halting problem, 309–312, 317
as metaphor, 312
Hamlet (Shakespeare), 146, 237, 254
in relation to *R&G*, 29, 33, 34, 36, 37, 236, 245, 264
Hapgood (Stoppard), 46, 49, 55–61, 63, 71–73, 206, 235, 304, 343
Hard Problem, The (Stoppard), 237, 272–277, 323, 328
Hardy, G. H., 2, 4–5, 7, 8, 11, 186, 225, 227, 228, 231, 234, 286, 291, 292, 340, 342, 344, *see also A Mathematician's Apology*, 364
biography of, 219–221
Haupton, Ira, 11
Havel, Václav, 47
Heisenberg, Werner, 203, 210, 215, 343
biography of, 205–206
science of, 211–213
Hilbert's decision problem, 290–291, 294, 309–312, 344
as metaphor, 308
Hilbert's program, 175–178, 290, 300
Hilbert, David, 10, 12, 176–177, 183, 286, 290, 295, 304, 309, 344
Hitler, Adolf, 118, 210, 216, 286
Hobbes, Thomas, 80
Hodges, Andrew, 286, 288, 305
Hofstadter, Douglas, 330, 365, 367, 368
on machine intelligence, 275–276
Housman, A. E., 279, 282
on meaning and poetry, 282
human implications of mathematics, 9, 11, 15, 22, 55, 58, 62, 67, 69, 72, 133, 135, 203, 212, 213, 234, 283, 294, 306, 312, 329, 330, 344, 346
hyperbolic geometry, 117, 121

I Am a Strange Loop (Hofstadter), 368
I is a Strange Loop (Gould and du Sautoy), 351
Ibsen, Henrik, 78, 79, 92, 113, 156
If You're Glad I'll Be Frank (Stoppard), 25
Imitation Game, The (Moore), 329
imitation game, *see also* Turing test, 322–324, 327, 333, 334
Importance of Being Earnest, The (Wilde), 264
In the Matter of J. Robert Oppenheimer (Kipphardt), 202
incompleteness, 15, 178, 236, 323, *see also* Gödel's Incompleteness Theorem
as metaphor, 169, 184, 272, 344
of PM, 183–185, 243, 262–263, 278
Independence of Triangles, The: A Play in Four Acts (Witkiewicz), 100
infinite series, 220, 229
Infinities (Barrow), 11
infinity, 15, 41, 44, 97–99, 101, 102, 121, 122, 180, 219, 224, 225, 229
and Cantor, 101, 225, 343, 362
intelligence
human, 273, 305, 322, 328, 333
machine, 274–276, 304, 305, 307, 320–329
Introduction to the Theory of Pure Form in the Theater (Witkiewicz), 104, 115, 124–126
Invention of Love, The (Stoppard), 279–282, 284

irrational numbers, 15, 137, 139, 173, 175, 177, 227, 230, 240, 359
as metaphor in Beckett, 137, 139, 167, 178, 343
Isaac's Eye (Hnath), 11
Isaacson, Barry, 367

Jacobi, Derek, 287
Jarry, Alfred, 11, 12, 87, 113, 118, 186
biography of, 89–91, 96
on surface of God, 97
on *Ubu Roi*, 92
Jefferson, Sir Geoffrey, 324
Joyce, James, 46, 135, 136, 145, 249
Jumpers (Stoppard), 21, 37–46, 48, 49, 71, 147, 235, 263, 273, 343

Königsberg, 56, 176, 290
bridges of, 56–57
Kant, Immanuel, 77, 118, 157, 176
Kaun, Axel letter, 129, 156, 162, 177
passages from, 144–145
Keaton, Buster, 161, 162
King Lear (Shakespeare), 29
Kipphardt, Heinar, 202
Klein bottle, 196
Klein, Felix, 196

Labouchere amendment, 284
Lambert, Johann, 105, 111
Langdal, Peter, 218
Langley, Samuel, 97
Laplace, Pierre Simon, 71
Leap (Gunderson), 11
Legendre, Adrien-Marie, 107
Let Newton Be (Baxter), 11
Life of Galileo (Brecht), 12, 187–190, 219, 287
Lobachevsky, Nikolai, 112, 117, 121, 343, 356
Locke, John, 80
logic, 15, 26, 30, 133, 134, 157–159, 177, 286, 304, *see also* completeness, consistency
formal, 38, 135, 169–175, 240, 363
symbolic, *see* formal
logography, 140, 145
Lord Malquist and Mr. Moon (Stoppard), 33
Lorenz, Edward, 63, 65
Love's Labour's Lost (Shakespeare), 34
Lovesong of the Electric Bear (Wilson), 11, 314–319, 325–330
Lucas, J. R., 367

M Is for Moon among Other Things (Stoppard), 25
Macbeth (Shakespeare), 91, 132
MacColl, Ewan, 202
Madman and the Nun, The, or There Is Nothing Bad Which Could Not Turn into Something Worse: A Short Play in Three Acts and Four Scenes (Witkiewicz), 100
Magritte, René, 247, 252, 267
Malone Dies (Beckett), 137, 359
Mandelbrot, Benoit, 20, 65
manifold, two-dimensional, 195
Mathematician's Apology, A (Hardy), 2, 5, 7, 186, 219–221, 225, 226, 228, 340, 364
McBurney, Simon, 2–3, 11, 12, 343
on creativity, 232
origins of *A Disappearing Number*, 219, 222, 229
relationship to mathematics, 223–225
Menaced Assassin, The (Magritte), 249
Mendés, Catulle, 91
Mendelsohn, Daniel, 281
Mercier, Vivian, 147
metalanguage of formal systems, 243
metamathematics, 10, 243, 263, 275, 278, 282, *see also* reflexive devices in mathematics, self-reference
Metaphysics of a Two Headed Calf: A Tropical Australian Play in Three Acts (Witkiewicz), 100
metatheater, 10, 269, 272, *see also* reflexive devices in theater, self-reference
in Beckett, 154, 155, 237

in Stoppard, 235, 237, 244–252, 263
in *A Disappearing Number*, 226
Mighton, John, 285, 332, 334, 370
biography of, 330
minimalism
in Beckett's plays, 147, 178
of *Copenhagen*, 216
Miss Julie (Strindberg), 78, 266, 271
Möbius, Alfred Ferdinand, 189, 194
Möbius strip, 195–197, 200, 201, 343, 363
Molloy (Beckett), 9, 137, 180, 182, 183, 359
Moore, G. E., 352
Morcom, Christopher, 288, 293, 308, 315
More Pricks Than Kicks (Beckett), 136
Murphy (Beckett), 12, 136–141, 180
music, 4, 46, 141, 367
Beckett and, 144, 164
percussion, 132
Pythagoreans and, 137
Stoppard and, 46
tabla, 229
musical, 11

Nagel, Ernest, 367
Nash, John, 338
National Theatre (London), 2, 18, 34, 38, 61, 216
natural numbers, 157, 168, 231, 302, 361
formalized in PA, 238–243
in mathematical realism, 182
von Neumann, John, 291, 304
Newman, James, 367
Newman, Max, 290, 294, 302, 325
Newton's Hooke (Pinner), 11
Newton, Isaac, 11, 34, 35, 62, 68, 71, 72, 80, 94, 108, 113, 118, 189, 201, 208, 225
Night and Day (Stoppard), 48
non-Euclidean
geometry, 4, 9, 15, 73, 98, 105–112, 125, 133, 343
psychology, 122
theater, 13, 100, 113–117, 125, 126
Norman, Marc, 271
Not I (Beckett), 163–166, 178, 180, 186
nuclear bomb, 190, 192, 194, 202, 210, 215, 216
Nude Descending a Staircase (Duchamp), 250
Number, A (Churchill), 13
number theory, 132, 177, 229, 260, 277, 300, 362

Oedipus Tyrannus (Sophocles), 7, 201
On the Razzle (Stoppard), 48
orientable surface, 195
Osborne, John, 24
Oulipo, 97
Oxford, 226, 279, 292
Oxford Theatre Group, 33

painting, 62, 354, 367
and Beckett, 144, 167
and Stoppard, 248, 250, 267
and Witkiewicz, 125
of paintings, 237, 252
Paltrow, Gwyneth, 336
paradox, 15, 22, 25, 37, 59, 102, 112, 133, 134, 147, 151, 153, 163, 166, 182–185, 191, 192, 194–196, 246, 247, 312, *see also* Epimenides paradox, Russell's paradox, Zeno's paradox
parallel postulate, *see* Euclid's fifth postulate
Parker, Mary-Louise, 336
Parmenides, 42
Partitions (Haupton), 11
partitions, 11, 219, 227, 230
pataphysics, 89, 93–94, 97, 113
Peano Arithmetic, 238–244, 361
Peano, Giuseppe, 238, 361
perfect numbers, 259
performativity, 213, 363
Péron, Alfred, 141
Philosophical Investigations (Wittgenstein), 255
philosophy, 38–46
Cartesian, 137
empirical, 34, 35, 39, 44
of immaterialism, 150, 219

philosophy (*continued*)
of nominalism, 145, 157
positivist, 49, 352
surrealist, 88, 97, 247
Physicists, The (Dürrenmatt), 189–202, 219
Picasso, Pablo, 97
Pinter, Harold, 24
Pirandello, Luigi, 237
Planck's constant, 212
Plato, 6, 42, 76, 156
Platonic solids, 80, 93, 94
Poetics (Aristotle), 6, 7, 126, 357
poetry, 7, 27, 146, 153, 254, 279–283, 317, 320, 321
Poincaré, Henri, 111, 357
21 Points to The Physicists (Dürrenmatt), 190–192, 200
postmodern, 36, 166
Postulate 5, *see* Euclid's fifth postulate
postulates, *see* axioms
Poussin, Nicolas, 62
Previn, André, 46
prime numbers, 175, 219, 221, 240, 259–261, 300, 337, 339, 368
Germain, 339
primitive propositions, 169, *see also* axioms
Principia Mathematica (Russell and Whitehead), 13, 45, 71, 81, 119, 134, 160, 168–178, 184, 236, 238, 261, 282, 283, 304, 316, 367
probability, 21, 30–32, 35, 48, 186
in quantum mechanics, 207–214
Problems of the Theater (Dürrenmatt), 190
Proclus, 84, 106
Professional Foul (Stoppard), 47
Proof (Auburn), 11, 13, 336–342, 344–346
proof, 6–10
by contradiction, 86, 358
in PA, 240–243
in PM, 171–173
of $1 + 1 = 2$, 238, 241
of angle sum of a triangle equals 180°, 86
of Fermat's Last Theorem, 18
of Gödel's Incompleteness Theorem, 183–184, 257–263
of irrationality of $\sqrt{2}$, 358
of the halting problem, 311
Ptolemaic system, 187
pure form, 104, 115, 124
description of, 124–126
Pythagoras, 137
Pythagorean Theorem, 6, 18, 81, 83, 97, 137

Quad (Beckett), 12, 129–133, 178–182
quantum mechanics, 49–56, 61, 71–73, 192, 203, 207–219, 230
entanglement in, 218
Quine, W.V.O., 367

radio play, 21, 24, 218, 249, 251, 252
Ramanujan, Srinivasa, 219, 340
biography of, 224, 225
death of, 228
taxicab story, 231
work on partitions, 227
working method of, 231
rational numbers, 137, 139, 167, 178
Real Thing, The (Stoppard), 48, 264–272, 278, 333
Real Inspector Hound, The (Stoppard), 245–247, 261, 277
realism, 94, 96
in mathematics, 10, 74–77, 79, 83, 113, 117, 133, 156–159, 182, 223
in philosophy, 145
in theater, 8, 10, 77–80, 92, 104, 113, 118, 125, 317
reflexive, *see also* metamathematics, metatheater, self-reference, 346
devices in art, 252
devices in mathematics, 36, 160, 252
devices in neuroscience, 237
devices in theater, 12, 155, 236, 246
relativity, 8, 80, 104, 118, 211, 292, 322

Riemann Hypothesis, 329, 338
Riemann-zeta function, 221, 223, 225, 330
Romantic thinking, 62–64, 77, 279, 354
Rosa, Salvator, 62
Rosencrantz and Guildenstern Are Dead (Stoppard), 21, 24, 29–37, 235, 238, 245, 247, 252, 264, 265
  film version, 35–37
Russell's paradox, 156–160, 166, 184, 245, 343
Russell, Bertrand, 10, 12, 45, 71, 80, 101, 125, 156–160, 162, 168–175, 177, 182, 183, 236, 238, 255, 282, 304

Saccheri, Girolamo, 105
Salazar-Sutil, Nicolas, 117, 355–357, 362, 365
du Sautoy, Marcus, 226, 227, 230, 351, 364
Schneider, Alan, 162, 360, 361
science theater, 13, 188, 191, 202, 204, 213, 218
  use of form and content, 203
Second Law of Thermodynamics, 20, 63, 68, 69
self-reference, 134, 160, *see also* reflexive, metatheater, and metamathematics
  in Beckett, 154, 160, 166
  in logic, 160, 162, 236
  in PA, 269, 275
  in PM, 184, 236, 244, 259, 261, 283
  in riddles, 159
  in Stoppard, 236, 237, 259, 264–272, 277
set theory, 158, 357
Shakespeare in Love (Stoppard and Norman), 271
Shakespeare, William, 23, 29, 32, 36, 37, 91, 132, 146, 237, 253, 254, 270, 285, 320, 353, 365
Shambhu, Shane, 229
Shaw, George Bernard, 113
Shepherd-Barr, Kirsten, 68, 204, 213, 218, 363, 364
Shropshire Lad, A (Housman), 279
Silent Sky (Gunderson), 13
Six Characters in Search of an Author (Pirandello), 237
Skyscraper (Auburn), 336
Sluts and Butterflies: A Comedy with Corpses in Two Acts and Three Scenes (Witkiewicz), 100
Smith, Anthony, 28
Snow, C. P., 222, 226
Solomon, King, 194, 200, 201
sphere, 121–122, 195, 196, 354
spherical geometry, 121
Spinoza, Baruch, 81
Squaring the Circle (Stoppard), 47, 244–246
Stanislavski, Konstantin, 78
Stein, Gertrude, 145
Stevenson, Shelagh, 13
Stoppard, Tom, 3, 10–12, 15, 19, 21, 343
  and language, 38, 45
  biography of, 21–25
  on Beckett, 147
  on mathematics of uncertainty, 48
  on metanarratives, 277
  on *Arcadia*, 21
  on *Hapgood*, 60
  on *Jumpers*, 37
  on *R&G*, 29–30, 33–34, 37
  on *The Real Thing*, 264, 265
Strindberg, August, 78, 79, 113, 266
sufficiently powerful
  artistic interpretation of, 278, 283
  with respect to PM, 177, 277, 368
surd, 139
symmetry, 4, 132, 133, 179, 182, 230

table of behavior (for a Turing machine), 296–300
Tandy, Jessica, 164
Thales, 351
theorem in a formal system, 171, 240
theorem numbers, 259
Theory of Parallels (Lambert), 105

thermodynamics, 68, 71, 72
tihai, 229
'Tis Pity She's a Whore (Ford), 265
Tonning, Erik, 180
Tony Award, 217, 265, 336
topology, 195, 201, 204
transformation rules in a formal system, 171, 172, 174, 240–242, 274, 276, 366
Traveling Salesman Problem, 11
Travesties (Stoppard), 46, 49, 249, 264
triangle
  and the Holy Trinity, 97
  angle sums equal 180°, 86, 110, 125
  angle sums greater than 180°, 108, 122
  angle sums less than 180°, 109
  love, 137
  musical, 46
  right, 18, 81
  similar, 106, 109, 356
Truth Values: One Girl's Romp Through the MIT Male Math Maze (De Cari), 13
Tumor Brainiowicz: A Drama in Three Acts with a Prologue (Witkiewicz), 100–104, 111, 115
Turing machine, 286, 295–305, *see also* universal machine, 329, 330
  and the halting problem, 309–312
Turing test, 286, 319–323, 330–334
Turing's thesis, 286, 300
Turing, Alan, 11, 12, 15
  apology to, 335
  biography of, 285, 288–292, 313, 317, 327
  death of, 285, 313
  from *Computing Machinery and Intelligence*, 323–325
  on Christopher Morcom, 289
  on intelligence, 324
  on the halting problem, 311
  on the imitation game, 323
  radio debate, 325
  verse of, 318
  working methodology, 329
Tynan, Kenneth, 34
Tzara, Tristan, 46, 249

Ubu Cocu (Jarry), 92–95, 186
Ubu Roi (Jarry), 12, 87–92, 96, 186
uncertainty, 8, 9, 22, 27, 35, 48, 70–72, 103, 134, 211, 212, 342–344
uncertainty principle, 203, 211
  for human introspection, 213, 218
undecidable, in PM, 176, 184, 236, 269, 275, 363
universal machine, 300–304, 307, 309, 311, 312, 327, 330
Unnamable, The (Beckett), 129, 137, 181, 359
Uranium (MacColl), 202

Virgil, 132
Visit, The (Dürrenmatt), 188

Waiting for Godot (Beckett), 15, 129, 146–148, 150, 152, 153, 160, 162, 166, 180, 186, 353, 360, 365, 368
Walesa, Lech, 47, 244
Walk on the Water, A (Stoppard), 24
Wallis, John, 106
Wardle, Irving, 49
Water Hen, The: A Spherical Tragedy in Three Acts (Witkiewicz), 100, 119–124, 127, 128, 236
Watt (Beckett), 137, 141–144, 146, 178, 179, 359, 365
wave function, 207–208, 210
  for human introspection, 218
wave/particle duality, 50–55, 206
  in *Copenhagen*, 203
  in *Hapgood*, 59
Wertenbaker, Timberlake, 13
Whitehead, Alfred North, 160, 162, 169–175, 236

Whitelaw, Billie, 164, 362
Whitemore, Hugh, 285–289, 304, 305, 312, 313, 330, 334, 344
whole numbers, *see* natural numbers
Wilde, Oscar, 278, 280, 281, 285
Wiles, Andrew, 18, 19, 21, 310
Wilson, Snoo, 285, 314, 318, 319, 325, 327–329, 344
Witkacy, *see* Stanislaw Witkiewicz
Witkiewicz, Stanislaw, 11–13, 74, 80, 112, 186, 233, 343
  artistic vision of, 100
  biography of, 99–100
  death of, 128
  on pure form, 115, 124–126
  on *Tumor Brainiowicz*, 104
  year of Witkacy, 104, 128
Wittgenstein, Ludwig, 38, 40, 177, 286, 307
  builders language game, 255–256
women playwrights, 13

Zakopane, Poland, 99, 128
Zeno of Elea, 42
Zeno's paradoxes, 38, 49, 51, 71, 147, 150, 343
  of Achilles and the Tortoise, 45
  of the Arrow, 44
  of the Millet Seed, 147, 343
Zwick, Ed, 270