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The Fields of Light

Peter D. Pešić

> *Socrates:* Then just take a look round and make sure that none of the uninitiate overhears us. I mean by the uninitiate the people who believe that nothing is real save what they can grasp with their hands and do not admit that actions or processes or anything invisible can count as real.
> *Theaetetus:* They sound like a very hard and repellent sort of people.
> *Socrates:* It is true, they are remarkably crude.
>
> Plato, *Theaetetus* (155e)

Those who reflect on physics often express a certain dismay at what seems the aridity of the "new science" that began with Descartes's project of a mechanical understanding of Nature. Granted that its results are imposing and powerful, the question remains: What is *interesting* about it? Here *interest* bears its original economic sense, as when capital yields interest. In this usage the Latin *interesse* signifies the emergence of new and different accrual to the initial deposit of an idea. It denotes something novel, even surprising, proceeding from given premises. This essay will try to show how the attempt to describe Nature solely in terms of palpable matter leads, through its own inner development, to a new understanding that transcends matter. To put it tersely, matter is not material. It calls forth a new mode of being, the field, which ultimately eclipses matter itself.

The question concerning the nature of light reveals this shift with particular clarity and was in many ways also the ground for its occurrence.

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This essay is based on a lecture delivered at the Santa Fe campus in April, 1984. It is dedicated to the memory of the author's father, Paul Pešić (1912–1988).

Lucretius can stand here as an exponent of the initial thrust of these accounts. Following Epicurus, Lucretius suggests that an object sends out films of atoms which detach themselves from its outer surface and float outwards.[1] Some of them, quite by accident, encounter the eye and give rise to the visual image. Others, impinging upon ears or nose, give rise to sounds or smells. This account may be contrasted with the hypothesis Plato entertains that the eye itself sends out rays whose encounter with the object constitute vision.[2] The *activity* of the eye in Plato's account is essential. For Lucretius the eye is a *passive* receptor that converts the impinging atoms into the visible sensation. Thus he explains vision in terms of traveling material substances.

His account is in many ways similar to the account Newton offers much later in his *Opticks.* However, for Newton the light is not simply atoms from the surface of the body that enter the eye. He speculates that the rays of light are "very small bodies emitted from shining substances."[3] The light is distinguished from the shining substance that emits it. As Newton writes:

> The changing of Bodies into Light, and Light in Bodies, is very conformable to the Course of Nature, which seems delighted with Transmutations. . . . Eggs grow from insensible Magnitudes, and change into Animals, Tadpoles into Frogs, and Worms into Flies. . . . And among such various and strange Transmutations, why may not Nature change Bodies into Light, and Light into Bodies?[4]

It is noteworthy that Newton chooses these organic images of transformation in describing the behavior of light rays, themselves composed of inorganic bodies regulated by mathematical principle.

A crucial similarity to Lucretius nonetheless remains: Light is "very small Bodies" traveling until they impinge upon the eye, which is a material structure also. Many powerful conclusions flow from this approach. Color, for Newton, results from the different sizes of the light particles. Refraction results from the acceleration of these particles as they move from air into glass or water. A comprehensive account is formed that seems to encompass all known optical phenomena. Yet, as Newton admits, the only sure account is really a mathematical description of the phenomena which leaves largely unknown the underlying physical reality, just because he will "feign no hypotheses" concerning the forces he describes in the theorems. In his Queries, however, Newton suggests that particles of light will now most readily account for the theorems he proved earlier when speaking of rays of light. These rays are mathematical entities which he had discussed as such without needing to specify their nature. For Newton, there is a difference between the assurance with which he speaks of the mathematical properties of the rays and the diffidence with which he speculates that the rays are composed of particles.

But, as Newton starts to speak of the manner in which glass or water affects the rays so as to cause the appearance of refraction, he remarks that these substances "act upon the Rays of Light at a distance . . . and this Action and Re-Action at a distance very much resembles an attractive Force between Bodies."[5] He makes similar assertions elsewhere that the force of gravity also and perhaps all forces between bodies seem to act at a distance. That is, one body can affect another, distant body in a manner that simply depends on the distance between them. For Newton, it would go too far, at this stage at least, to assert that such a force must necessarily *travel* somehow between the bodies. Mathematically, it seems to act at a distance, and we should not then "feign the hypothesis" that such action at a distance then implies transmission of the force passing in some describable way through the space intervening between the two bodies.

So in his public writings Newton felt that describing gravitation or the action of glass upon a light ray as action at a distance was all he could do with full circumspection. But privately Newton felt the necessity to go further. In a celebrated letter to Bentley he wrote that

> it is inconceivable that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact, as it must do if gravitation, in the sense of Epicurus, be essential and inherent in it. . . . That gravity should be innate, inherent and essential to matter, so that one body can act upon another at a distance, through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it.[6]

In some of his Optical Queries Newton tried to account for gravitation in terms of the pressure of some medium, but much of this work he left unpublished because, as Maclaurin wrote, "he found he was not able, from experiment and observation, to give a satisfactory account of this medium, and the manner of its operation in producing the chief phenomena of nature."[7] So for Newton, at least, the attempt to advance the Lucretian notion that light is simply a stream of small bodies led to the need for some sort of mediation of the forces acting between bodies. Newton felt that such mediation required some sort of medium, and that medium baffled him.

In reaching this impasse, Newton considered and rejected the suggestion of Huygens that presumed the existence of a universal medium or aether, and described light as waves traveling through this medium, much as water waves represent a state of vibration which passes through the medium of water.[8] Huygens imagined the space between bodies as packed with small, hard particles of equal size. When a body began emitting light at some point, he considered that these ether particles would transmit a shove much as a pool table packed with billiard balls would transmit an impulse imparted to some ball at the edge of the table.

But Newton replied:

> A dense Fluid can be of no use for explaining the Phaenomena of Nature, the Motions of the Planets and Comets being better explained without it. It serves only to disturb and retard the Motions of those great Bodies, and make the Frame of Nature languish . . . so there is no evidence for its Existence, and therefore it ought to be rejected.[9]

Such a dense medium is for Newton the prime example of a "feigned hypothesis," as he terms it, which turns from the appearance of empty space to the daring and questionable supposition of an invisible and dense ethereal medium pervading space. Thus for Newton the notion that rays of light are "very small Bodies emitted from shining Substances"[10] is vastly preferable.

Though he rejects the dense medium he felt was necessary for Huygens's theory, Newton nonetheless did not hesitate to argue for a "much subtiler Medium than Air, which after the Air was drawn out remained in the Vacuum."[11] He argues that this subtle, rarefied medium would give way before the passing planets and not disturb their orbits, and its varying density would explain the refraction of light and the transmission of heat. All this seems less paradoxical when Newton asserts that his ethereal medium is not like that of Huygens, "which fills all Space adequately without leaving any Pores, and by consequence is much denser than Quick-Silver or Gold."[12] The resistance of Newton's ether would be inconsiderable, he argues, because it is so rarified. There are void spaces between the ether particles which permit Newton's ether to be more or less rarefied or compressed. Those void spaces allow his ether to slide around the planets without hindering them, whereas Huygens's picture fills space with particles densely packed with no space between them.

Thus one comes to see that Newton's ether is not in his eyes a feigned hypothesis, because it seems to him unavoidable in explaining the refraction of light and yet does not impede the motion of bodies. But that leaves him in the quandary about how forces act between the particles of material bodies. For Huygens, bodies act by direct contact, and not at all at a distance. For Newton, it would seem that, finally, bodies can only act at a distance, since he does still require the empty spaces between bodies. But, as Newton himself admitted in the letter we cited earlier, such a notion of action at a distance is disturbing and mysterious. To quote him again, "It is inconceivable that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact . . . ." These words, "the mediation of something else, which is not material," are thrown into even higher relief. Newton seems to understand that this mediation is not simply by means of a material medium. That is, if for instance we consider that two bodies exert forces on each other by sending little particles out, we are still left with the problem of how these little particles act, by direct contact, or at a distance. So there is no escape from our problem of how bodies exert forces on each other simply in postulating even smaller particles that somehow accomplish this mediation. Eventually, we must face the question: action at a distance or direct contact?

Huygens's notion of direct contact would seem satisfying except for Newton's objections and the further problem of the unyielding hardness of the particles that is required. For imagine two bodies coming into contact. If they are not absolutely rigid and hard, there is a certain delay from the moment of first contact and the resulting recoil. That implies a certain *mediation* of the directness of contact. Even worse, when is the exact moment of contact? The edges of the bodies would have to be perfectly sharp and square for one to be able, even in the imagination, to assign a true moment of contact, rather than a certain interval during which they contact each other and interact. Perhaps our problem would disappear if we were to treat each body as a Euclidean point, much as Newton teaches us to do in the *Principia.*[13] But it is very disturbing to think that the force only springs into existence in the moment of contact, when the two points coincide. For if two points coincide, they are really not two points, but one point. And how can one point exert a force on itself? Or what sufficient reason would give the magnitude of such a force, exerted by a dimensionless body at no distance? On the other hand, if the two points do not coincide, our supposition of force as direct contact would say they cannot exert any force on each other! As if this were not difficult enough, our picture of material bodies as points, which we required in order to speak exactly of contact between bodies, is really a mathematical representation only, as Newton says. The bodies we are familiar with are irregular and rough and hence couldn't simply be treated as points, even if the argument about points would have worked! Another way of putting this is that even if I envision a body as composed of point-like atoms, those points could never touch.

I am left with the strange and disquieting conclusion that no material bodies have ever touched, in the sense that I cannot find the moment of contact even if I picture the bodies as points or composed of points. Perhaps difficulties such as these moved Newton to speak of action at a distance, since no simple hypothesis of action by contact will do. Yet it was the inscrutability of action at a distance that made him speak of "the mediation of something else, which is not material . . . ."[14] This mediation offers a reasonable escape from our dilemma. If action by contact is fallacious, then the mediator cannot be material but must be "something else." This leads to the conclusion that the natural philosophy of matter cannot remain complete without invoking a mediation that is not material. So matter must point beyond itself.

The full implications of such a statement must rest on inquiry into what we mean by "matter." The rough sensual description of matter as something weighty, and able to be touched, seen, and smelled, obviously begs the question, since we must refer to organs of sensation or measurement which are themselves material. By speaking of it in terms of interactions between material objects and material measuring instruments we still beg the question of matter (by itself, in itself). In a celebrated passage, Newton writes that

> All these things being consider'd, it seems probable to me, that God in the Beginning formed Matter in solid, massy, hard, impenetrable, movable Particles . . . and that these primitive Particles being Solids, are incomparably harder than any porous Bodies compounded of them; even so very hard, as never to wear or break in pieces; no ordinary Power being able to divide what God himself made one in the first Creation.[15]

What these particles are, or are made of, would seem almost an inadmissible question, if they are to be the primitive, most basic constituents. Yet if they are not simple points and have some size, we surely must entertain the question of what forces between the points of these atoms make them so extraordinarily hard. The atom seems to dissolve into a constellation of immaterial forces. Even were the atom utterly dimensionless and point-like, we would have the pregnantly absurd situation of matter, which presumably occupies space, occupying no space at all! And if the atom is extended in space, we can still speak of the distance between certain points within the atom, or the forces between these points. But we have just shown that there can be no matter simply at a point. If we cannot say that there is matter at any point, where then is it?

Our problem reflects an ambivalence in Newton's own thought between the material, physical world and the mathematical principles, which speak of forces that are not material but mathematical entities. In this mathematical view mass itself is a pure magnitude and not palpable stuff. In speaking of hard particles Newton means, I suppose, to return to the world of experimental appearance from the world of mathematical principles. Even though he wishes to show that the mathematical principles guide and describe the observed motion of bodies perfectly, yet the language and rhetoric of mathematics jar against that of "stuff" and matter. It was Kant's insight at this point to say that what we can know of matter is force and only force. To attempt to speak of matter in itself, beyond the character of the forces experienced, is to ask to know something beyond our capacity. Kant goes on to argue that an absolute and empty space through which Newton's action at a distance might act is "nothing at all belonging to the existence of things."[16] These powerful observations were to a great degree ignored by practicing scientists of the time, though it must be said that Kant's teaching of the primacy of forces in natural philosophy had an immense influence through the German *Naturphilosophie.* I would suggest that the heart of field theory, and even of relativity and quantum theory, lies implicit and foreshadowed in Kant's deep insights. Indeed, I do not think that modern natural philosophy has yet by any means exhausted the depths he pointed out.

Let me turn from Kant and return to Newton's thought that it does make sense to speak of "solid, massy, hard, inpenetrable particles." What is it that makes us so sure that "brute inanimate matter," as Newton calls it, really must be part of our conception of the world? We seem to pay respect to our sensations and give them credit, as it were, by referring them to a thing, matter, which is the true source of smells, tastes, and sights. But our argument has led us to see the solid mass of matter dissolve into a web of interacting forces. Why do we continue to speak simply of matter? Perhaps because it would seem like an insult to our senses if we denied them an external source and origin.

Nevertheless, even with the greatest enthusiasm for a notion of matter and of primitive particles such as Newton had, we have been led to consider a maze of forces as the key to the behavior of matter, as if matter—even if we should cling to this notion—were finally at the disposal of the forces and wholly guided by them. Whether we begin with streams of light particles, as Newton does, or with an undulating medium, the mystery of light is contained in that non-material mediation which is the actuality of the reception of the hypothetical light particles or of the hypothetical wave. Finally, there is always a gap across which a leap, an act of mediation, must occur.

It is here that Aristotle helps, in a way that shows that the interweaving of these themes is not merely historical but even more richly complex. I present it here intentionally out of chronological order to stress the timelessness of the insight. In *De Anima* Aristotle has much to say about vision that speaks eloquently to the point we have reached in our inquiry. Light, he says, is "the activity [*energeia*] of the transparent in that [it is] transparent."[17] He, too, understood that it is in the transparent, seemingly empty, gap that the true nature of light lies. Light is "neither fire, nor in general any body, nor an emanation from any body (for in that case it would be a body of some kind), but the presence of fire or something of such kind in the transparent."[18] He goes on to explain that, since in his view there are no void, empty spaces, there is no space for another body to enter in. So light cannot simply be a body, for it would have to be at the same place as other bodies (the air, for instance) at the same time. Rather, light is *energeia*, a word closely related to work and activity, and is the particular activity of the transparent medium he calls *metaxu*, literally the "in-between." It is not this *metaxu* that is light, but rather light is a kind of activity or energization which is perhaps best expressed by the way Aristotle speaks of *energeia* elsewhere throughout his works. One gets the sense of maturity, of coming to full bloom, of a process or an organism coming into its full estate. Aristotle also observes that "matter is relative to some thing," signifying that matter exists in a state of *relation* to form and purpose.[19] He does not consider that it exists apart from these larger relations.

In the case of light, Aristotle speaks of a state of being energized and active which applies to this transparency between seer and object. This energization of the in-between zone seems to tally with the sort of "non-material mediation" Newton was groping for. Yet there are many divergences also: Newton's light particles travel in a void, while Aristotle's light is the energization of a region replete with substance, not void anywhere. In that respect Aristotle seems much closer to Huygens's picture of a dense medium through which vibrations pass. So Aristotle's view emerges as an immensely suggestive synthesis, before the fact, of Newton's play of forces (which he might understand as a sort of *energeia*) and Huygens's vibrating medium.

This constellation of accounts seems in want of further development, and indeed it is Newton who finds the crucial issue. In criticizing Huygens he remarks that if light were wavelike motion propagated through a fluid medium, like water waves, it would necessarily follow that light should not simply travel in straight lines but rather bend around obstacles just as water waves do. As he puts it,

> The Waves on the Surface of stagnating Water, passing by the sides of a broad Obstacle which stops part of them, bend afterwards and dilate themselves gradually into the quiet Water behind the Obstacle. The Waves, Pulses or Vibrations of the Air, wherein Sounds consist, bend manifestly, though not so much as the Waves of Water. For a Bell or a Cannon may be heard beyond a Hill which intercepts the sight of the sounding Body, and Sounds are propagated as readily through crooked Pipes as through straight ones. But Light is never known to follow crooked Passages nor to bend into the Shadow. For the fix'd Stars by the Interposition of any of the Planets cease to be seen.[20]

This would seem a critical problem, since Huygens also admitted that light seems to travel in straight lines, and he had to resort to rather tortuous and unconvincing arguments to make his light waves not seem to do just what Newton argued they might do. Thomas Young first observed phenomena that indicated that light does not simply travel in straight lines but indeed bends around obstacles just as Newton said that it would do if it were a wave. This seemed to be the moment of triumph for Huygens's notion of a vibrating medium, and of disgrace for the Newtonian picture of light as a particle. In the century following Young's first experiments, the great drama of the elaboration of the theories of electricity and magnetism unfolded, led by Faraday and Maxwell, leading to a notion of light as a wave composed of electric and magnetic fields.

What are these fields? In them may be the reappearance of Aristotle's notion of *energeia*, its phoenix-like rebirth after centuries in which Aristotle's physical thought was usually said to be simply wrong, dead, and useless. This may be an example of how the process of thought does not unfold simply historically, the later views a product of what preceded them. Aristotle grapsed an essential facet of the problem of light in a way one appreciates more fully after reading Newton, Huygens, and Maxwell.

The term field in this sense was in essence created by Maxwell, but it emerges from Michael Faraday's earlier discussions of what he called lines of force. The nuance is, I think, crucial and reveals much about Faraday and Maxwell. The son of a blacksmith, and himself a bookbinder's apprentice, Faraday became a laboratory technician at the Royal Institution in London. Through many years of reading and ceaseless experimentation, he became a great luminary of European science.

He hated the term "physicist," which had only recently (1830) been coined by Whewell, and wished to be, and to be called, a philosopher, an "unmathematical philosopher"[21] to boot, quite uneducated mathematically and separated from the great tradition of mathematical physics that Newton inaugurated with his *Principia*. Faraday wrote no treatise as Newton and Maxwell did, but left instead his episodic *Experimental Researches* and his *Diary*. As Thomas Simpson has written, these works were

> not theory, but a vast weaving and unweaving of suspected powers, a process of continual discovery and identification, a great, highly unified formulary for the production and classification of effects . . . . [He] is the great 'discoverer'; the paradigm for Faraday is Odysseus rather than Euclid: in a sense he, too, travels from land to land, reporting wonders, guided by legend and myth, rumor or divine love. For Odysseus, the dominant desire is to see men's cities and to know their minds, and to gather all this together in the return to Ithaca. For Faraday, it is to investigate all the powers of nature and to unveil them as esssentially one in the lecture hall on Albemarle Street.[22]

Faraday was the most practical of men and intensely attentive to the vivid detail of experimental phenomena. He was a true virtuoso of experiment, insightful and indefatigable, and endlessly inventive. He grew up with notions of electricity and magnetism as palpable and ponderable stuff. Yet this immensely practical and clear-sighted man gradually convinced himself that the true seat of electric and magnetic effects is the space surrounding electrified or magnetized bodies, whether that space be filled with some noticeable substance like air or seemingly empty.

Strange, is it not, for such a man to pass from the palpable bodies he sees before him to consider instead the impalpable, empty space between? Yet it was many experiments that led him thither, perhaps the most pregnant being one of the simplest. Consider a magnet upon which have been sprinkled iron filings. These filings seem to align as if to outline invisible lines that characterize the magnetic force. The presence of the filings makes the force visible. Does it not seem inescapable, thought Faraday, that these same lines of magnetic force are present even before the filings have been introduced? Many other considerations, particularly the characteristic curvatures of the lines, moved Faraday to speak of the lines as "physically real."[23]

Further, he felt persuaded that there was no need to speak of electric or magnetic fluids or substances, that these lines of force were the real, the essential seat of electric and magnetic phenomena. He writes that "as magnets may be looked upon as the habitations of bundles of lines of force, they probably show us the tendencies of the physical lines of force where they occur in the space around."[24]

Faraday seemed happiest with a vision in which his physical lines of force arch through space, without even ether, invisible yet physical. His friend Maxwell, in an admiring letter, describes this vision: "You seem to see the lines of force curving around obstacles and driving plump at conductors, and swerving towards certain directions in crystals, and carrying with them everywhere the same amount of attractive power . . . ."[25] In many parts of his great *Treatise*, Maxwell frankly admits his debt to Faraday, making us feel that he had indeed realized Faraday's vision in a mathematical way that Faraday himself could not have achieved.[26] In his letter to Faraday, Maxwell goes on to say that

> you are the first person in whom the idea of bodies acting at a distance by throwing the surrounding medium into a state of constraint has arisen, as a principle to be actually believed in. We have had streams of hooks and eyes flying around magnets . . .; but nothing is clearer than your description of all sources of forces keeping up a state of energy in all that surrounds them . . . .[27]

Even this frank praise reveals something about the two men. Faraday's lines of force become, for Maxwell, the "state of constraint of the surrounding medium," which he feels has a mathematical form and which he calls a field. Those physical, yet immaterial, lines of force Maxwell understands as states of a medium and the fields are the states of polarization of that medium.

Though Maxwell describes himself as translating Faraday's ideas into a mathematical form, the differences between the two men are extremely interesting. Writing to the great theorist Ampère, Faraday himself remarks that

> I am unfortunate in a want of mathematical knowledge and the power of entering with facility into abstract reasoning; I am obliged to feel my way by facts closely placed together so that it often happens I am left behind in the progress of a branch of science, not merely from the want of attention, but from the incapability I lie under of following it, notwithstanding all my exertions. . . . I fancy the habit I got into of attending too closely to experiment has somewhat fettered my power of reasoning, and chains me down; and I cannot help, now and then, comparing myself to a timid ignorant navigator who, though he might boldly and safely steer across a bay or an ocean by the aid of a compass which in its action and principles is infallible, is afraid to leave sight of the shore because he understands not the power of the instrument that is to guide him.[28]

Faraday wrote to Maxwell, "I was at first almost frightened when I saw such mathematical force made to bear upon the subject, and then wondered to see that the subject stood it so well."[29] There is gentle irony here, as well as respect for the power of the mathematical symbols Maxwell was forging. Also, Faraday maintains a certain pride in the integrity of his own progress, even as he self-deprecatingly calls himself a "labourer." He knew the value of his labors, or at least felt serenely confident that posterity would sift the gold from the dross. Yet there is also the note of a wistful Moses, who sees the promised land from afar and recognizes that he will not himself enter into the fullness of it.

In the case of Faraday and Maxwell, the promised land was the fields of light. It was left for Maxwell, through the power of his mathematical symbols, to discern in exact mathematical detail how light might be the coupled undulations of electric and magnetic fields, how moving a charged body sends a wave down their lines of force, a wave we can perceive as light. Yet I must emphasize that, in his own way, without mathematics, Faraday found these fields of light. He says that "the view which I am bold to put forth considers, therefore, radiation as a high species of vibration in the lines of force which are known to connect particles. . . . It endeavors to dismiss the ether, but not the vibration."[30] It seems to me that this discovery may be more wonderful than Maxwell's mathematical deduction and translation, in the way that one admires the pioneer explorer even more than the settlers that follow him. But there are excellences in both men that should be savored. Together they saw how the field leaps free of its source and can travel through boundless space.

Maxwell followed Faraday also on a further flight of speculation. If indeed these lines of force flex far from any body and if their state of tension is the true seat of the electromagnetic interactions, perhaps the notion of electric charge as a sort of fluid or simple material substance should be abandoned. The true actuality of electricity, magnetism, and light lies in the mediating fields; matter and charge dwindle and disappear from sight. At first Maxwell tried to think of "empty space" as filled in imagination with gears and idle wheels, an elaborate mechanical structure that helped guide his understanding as he wrought his equations.[31] Though he cherished his gears and wheels, when he came to write his *Treatise* he omitted all mention of them, now relying on the finished mathematical structure. Maxwell continued to believe that there might be a physical ether of which the fields were states of vibration, even though he ceased describing it in simple mechanical terms. Here the practical Faraday is more visionary still, for Faraday understood the lines of force as themselves sufficient, without any need for an ether to give them substance and habitation. The lines of force, the fields as Maxwell thought of them, are all that is. The great project of the purely material and even mechanical understanding of Nature has demanded these immaterial mediators which at last have eclipsed matter.

It does seem very odd simply to discard matter in favor of ghostly fields. Here it is helpful to think of music. Victor Zuckerkandl has written that "music is movement of tones in dynamic fields."[32] Music is indeed in no single note, but rather it is in the web of interrelationships that can be aptly termed a field. That is, the music is also between the notes. There is no silence in the sense of a void, utterly blank. The silence that precedes a piece of music is part of it, as one realizes when watching the different silent gestures a conductor uses to give the up-beat that precedes the sounds. I suppose here is Aristotle's insight regarding the absence of utter physical nothingness in the world, of sheer emptiness. If we take either Faraday's or Maxwell's account, there is not nothingness anywhere, for the field is there. Aristotle has shown us how *energeia* must emerge from a prior state of preparation, of *dynamis*, and not from nothing. The contemporary quantum theory of fields has argued, in extending Maxwell's mathematical theory, that sheer emptiness is self-contradictory.[33] This agrees deeply with Aristotle and gives the sense that the seemingly empty space, the silence, is the heart of activity, of music.

At times this vital silence is brought before us with particular intensity. The silences of a great work of art are the seat of its mysterious power and deserve our closest attention. Let me give you an example. Schubert, in his next-to-last piano sonata, in A major (D.959), concludes with a rondo based on a theme he had written when he was twenty, and which also became the song "Im Frühling." Here is the theme as he first presents it at the beginning of the rondo (measures 1–16):

Here is how Schubert shows us this theme at the end of the movement, after many variations and vicissitudes (measures 328–347):

The silences form a final revelation of the inner life of the theme. In each silence something immense happens. We are plunged into the field of force that is the music, when the music stops—as it would seem—and yet evidently does not stop. It is like that when we look at the light which only exists in and by virtue of the so-called "empty space." Our experience, then, is a field.

Randomly bumping particles and mechanisms do not hold much prospect of touching the sort of beings we are, but speaking of fields is more like us. A field is most of all a state of inter-relationship which has an inner integrity. In grasping such connections, the human mind shows its affinity with the field.

Perhaps in closing we should recall Einstein's first encounter with an object suspended in a field—a simple magnetic compass which his father gave him at four or five years of age.

> That this needle behaved in such a determined way did not at all fit into the nature of events, which could find a place in the unconscious world of concepts (effect connected with direct "touch"). I can still remember—or at least believe that I can remember—that this experience made a deep and lasting impression upon me. Something deeply hidden had to be behind things.[34]

Recalling this in later life, he also remembered how he "trembled and grew cold."

Notes

1. Lucretius, *De Rerum Natura* IV, 42 ff.
2. Plato, *Theaetetus* 156d.
3. Isaac Newton, *Opticks* (New York: Dover, 1979), p. 370. This and most of the following passages can also be found in Peter Pešić (ed.), *Junior Laboratory Manual* (Santa Fe: St. John's College, 1986), 2 vols.
4. Newton, *Opticks*, pp. 374–75.
5. *Ibid.* pp. 370–71.
6. Isaac Newton, *Principia* (Berkeley: University of California Press, 1962), vol. 2, p. 634.
7. Cited by Maxwell in W. D. Niven (ed.), *The Scientific Papers of James Clerk Maxwell* (New York: Dover, 1965), vol. 2, p. 316.
8. See Christiaan Huygens, *Treatise on Light,* in *Great Books of the Western World* (Chicago: Encyclopedia Britannica, 1952), vol. 34, pp. 553–75.
9. Newton, *Opticks,* p. 368.
10. *Ibid.*, p. 370
11. *Ibid.*, p. 349.
12. *Ibid.*, p. 352.
13. Newton, *Principia*, vol. 1, pp. 19 ff.
14. *Ibid.*, vol. 2, p. 634.

15. Newton, *Opticks*, p. 400.
16. I. Kant, *Metaphysical Foundations of Natural Science* (Indianapolis: Hackett, 1985), p. 132. See L. Pearce Williams, *The Origins of Field Theory* (Langham: University Press of America, 1980), pp. 32–43. I have continued this inquiry in a forthcoming essay "The Principle of Identicality and the Foundations of Quantum Theory."
17. Aristotle, *De Anima* 418b 9–10.
18. *Ibid.*, 418b 14–17.
19. *Physics,* II, 194b 9.
20. Newton, *Opticks*, pp. 362–63.
21. See the valuable essay by Thomas K. Simpson, "Maxwell's *Treatise* and the Restoration of the Cosmos," in *The Great Ideas Today,* (Chicago: Encyclopedia Britannica, 1986), p. 226.
22. *Ibid*, p. 227.
23. Faraday, "On the Physical Lines of Magnetic Force," included with his *Experimental Researches in Electricity* in *Great Books of the Western World* (Chicago: Encyclopedia Britannica, 1952), vol. 45, pp. 816–19.
24. Faraday *Experimental Researches in Electricity* (New York: Dover, 1965), vol. 3, pp. 435–36.
25. L. Pearce Williams (ed.), *The Selected Correspondence of Michael Faraday* (Cambridge: Cambridge University Press, 1971), vol. 2, p. 882.
26. See, for instance, J. C. Maxwell, *A Treatise on Electricity and Magnetism* (New York: Dover, 1954), §528.
27. Faraday, *Correspondence*, vol. 2, p. 882.
28. *Ibid.*, vol. 1, p. 134.
29. *Ibid.*, vol. 2, p. 864.
30. Faraday, "Thoughts on Ray Vibrations," in his *Experimental Researches in Chemistry and Physics* (London: Taylor and Francis, 1859), p. 370 (reprinted identically by Culture et Civilisation, Bruxelles, 1967).
31. See his writings on the theory of molecular vortices to be found in Maxwell's *Scientific Papers*, vol. 1, pp. 451–88.
32. Victor Zuckerkandl, *The Sense of Music* (Princeton: Princeton University Press, 1959), p. 37.
33. See, for example, P.A.M. Dirac, *Quantum Mechanics* (New York: Oxford University Press, 1958 [4th edition]), pp. 306–10. I have also addressed this matter in a forthcoming essay, "Virtuality and the Paradox of the Vacuum."
34. See Einstein's "Autobiographical Notes," in P. A. Schilpp (ed.), *Albert Einstein, Philosopher-Scientist* (New York: Harper and Row, 1959), p. 9.

Brilliancies Involving Equilateral Triangles

Samuel S. Kutler

In the very first proposition of the *Elements*, Euclid constructs an equilateral triangle. Among the theorems that I know about involving equilateral triangles, the most brilliant are presented here. Although none of them appears in the works of Euclid, every one of them, I am convinced, would have delighted him. Most of the books listed in the bibliography are referred to in this article. They present beautiful mathematics that does not require many preliminaries.

I. Odom's Golden Section Theorem

When I wanted to construct a golden section on a simple plane figure, the finest example known to me before 1988 was the regular pentagon, where the diagonals, AD and CE of figure 1, cut each other in golden sections at the point K (*Elements* XIII.8). In the early 1980s George Odom found an even simpler and more elegant way to produce a golden section. Odom's theorem appeared as an elementary problem in *The American Mathematical Monthly*[1] in 1983. Since I do not always read or even skim through the *Monthly* any more, I would not have known about Odom's theorem at all if it hadn't been for David Fowler, who refers to the theorem both in an article in *Ancient Philosophy*[2], where I first saw the construc-

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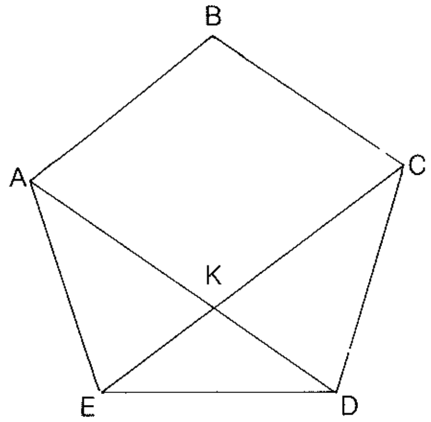

FIGURE 1. Diameters AD and CE cut each other at K in golden sections.

tion, and in his book entitled *The Mathematics of Plato's Academy.* Here is a statement of Odom's theorem exactly as it appeared as problem E3007:

> Let A and B be the midpoints of sides EF and ED of an equilateral triangle DEF. Extend AB to meet the circumcircle (of DEF) at C. Show that B divides AC according to the golden section.

Although no figure was published to accompany the problem, figure 2 is included here to illustrate Odom's theorem and to facilitate attempts by readers to find their own proofs. Both the solution that was published in the *Monthly*[3] in 1986, and another that is equally simple, appear at the end of this section.

Let us recall the definition of a *golden section* under one of its two other names. In the *Elements*, Euclid calls it *a line cut in extreme and mean ratio* and defines a straight line to be cut in such a ratio when

> as the whole line is to the greater segment, so is the greater to the less. [VI, def. 2]

Even before Euclid begins his treatment of ratio and proportion, he makes use of a line so divided to construct a regular pentagon. Consequently, he must give an equivalent ratio-free formulation:

> To cut a given straight line so that the rectangle contained by the whole and one of the segments is equal to the square on the remaining segment. [II.11]

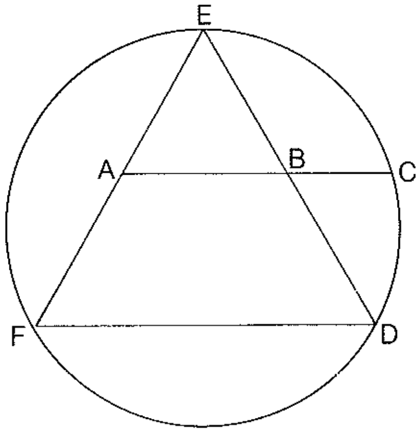

FIGURE 2. Odom's theorem: B divides AC according to the golden section.

The thirteenth and final book of the *Elements* concludes with the construction of the regular solids inscribed in spheres and the proof that "no other figure, besides the said five figures [pyramid, octahedron, cube, icosahedron, and dodecahedron] can be constructed which is contained by equilateral and equiangular figures equal to each other." The first six theorems of that book involve a line cut in extreme and mean ratio. In the analysis of these solids the golden ratio appears frequently. For example Euclid concludes his proposition 17 on the construction of the decagon with the insight that "when the side of the cube is cut in extreme and mean ratio, the greater segment is the side of the dodecahedron."

Another name for the *golden section* was given in the early sixteenth century. Fra Luca Pacioli published a book in Venice in 1509 (reprinted Milan 1956) on the golden section, with drawings by Leonardo da Vinci. Pacioli coins a name for what will later be called the golden section. It appears in his title: *De Divina Proportione.* Dan Pedoe quotes Johannes Kepler, who, in his own writings, adopts the name *divine proportion*, and writes about it (and *Elements* I.47) that

> Geometry has two great treasures: one is the theorem of Pythagoras: the other the division of a line into extreme and mean ratio.

In the second half of the twentieth century, H. E. Huntley adopts the name for his book: *The Divine Proportion*. Just as George Odom later finds the golden section using the circumscribed circle of an equilateral triangle, Huntley finds it in an inscribed circle of an almost-equilateral triangle (see figure 3, in which there is a doubled 3,4,5 triangle; that is to say, a 6,5,5 triangle).

Finally, the name *golden section* itself seems not to have been used until the 1830s in the second edition of a textbook by Martin Ohm. Professor R. Herz-Fischler, who published a history of the golden section[4] in 1987, speculates that rather than coining the term himself, Martin Ohm is citing a name that had recently come into current usage.

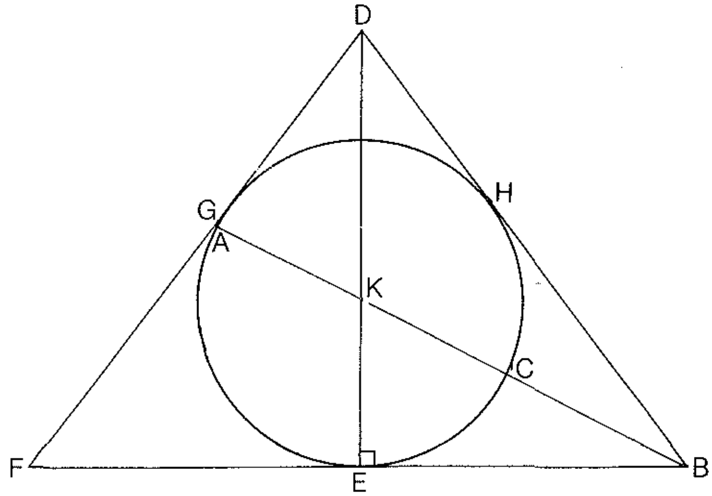

FIGURE 3. A golden section in a doubled 3–4–5 triangle.

BED is a right triangle with sides BE : ED : : 3 : 4.

Extend BE to F so that EF=BE, and join FD.

Let the bisector of angle B meet DE at K. Then K is the center of the inscribed circle to triangle BDF.

Inscribe circle GEH in triangle BDF, and let BK meet that circle at both C and A.

DK : KE : : BD : BE [VI.3], so that the diameter of the circle=BE.

The square on BE=the rectangle AB, BC [III.36]; that is,

AB : BE : : BE : BC; but BE is equal to the diameter AC, so that

AB : AC : : AC : BC, and AB is cut in a golden section at C.

Enough about names! When I saw Odom's theorem, I could no more get it out of my head than I can do so with certain tunes. At first I thought it was because this most important ratio of all was constructed with the very first figure that Euclid constructs: the equilateral triangle. Furthermore, nothing else was needed but a circumscribed circle and a straight line constructed through any two midpoints and continued, on one side or the other, until it reaches the circle. As Fowler put it in his article, "[this] surely must be its simplest construction." It took me days to realize that something else was bothering me. Theorems as simple and delightful as the one by George Odom are not what mathematicians are interested in these days; such discoveries are made in antiquity or its renaissance. Maybe I could find out how George Odom hit upon his construction. David Fowler left a clue in a footnote of his article:

> I first heard of this construction in correspondence with H. S. M. Coxeter; who was inquiring if anybody had come across it before. Coxeter had received it in a letter from George Odom.

For me at least, Harold Scott MacDonald Coxeter is the world's leading geometer. I was reluctant to bother him with my questions, but my curiosity overcame my reluctance, and I telephoned Professor Coxeter, whom I had met in 1972. What follows is an approximation of part of the telephone conversation:

SSK: Is George Odom a mathematician? HSMC: No, he is an artist with an amateur's interest in mathematics. SSK: Did he have a proof for his construction? HSMC: Yes, but not as elegant as the published one. SSK: Do you know how he discovered his theorem? HSMC: Yes, he was studying the icosahedron in my book *Regular Polytopes.* SSK: Do you think that perhaps one of the ancient Greek mathematicians had discovered Odom's theorem? HSMC: (Knowingly) No, I don't think so.

Since our conversation, I believe that I have figured out why Professor Coxeter seemed to be certain that this theorem was unknown until the 1980s: The construction is so simple and beautiful that it would have been shown from one friend to another, been written down many times, and survived.

Now, as I promised, I will present two proofs. The first is printed below figure 4. I have supplied the steps, since Jan van de Craats of the Netherlands submitted it as a "proof without words" and it was so published in the *Monthly* in the Aug.–Sept. issue in 1986. The second one, with figure 5, is an even shorter proof; it was submitted by David Fowler and others. It makes splendid use of Euclid's crossed chord theorem (III.35).

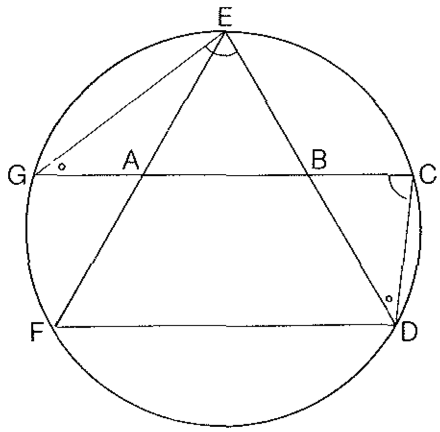

FIGURE 4. The proof of Odom's theorem by Jan van de Craats:

For the proof, modify figure 2 by continuing CA to the circle at G and construct GE.

Angles GEB and BCD are equal, since they stand on equal circumferences. So are angles EGB and BDC.

Then triangles GBE and BDC are equiangular and hence similar:

GB : EB : : BD : BC, but GB=AC, EB=AB, and BD=AB; so that

AC : AB : : AB : BC, and AC is cut in a golden section at B.

I myself found a three-circle construction of a golden section on Saturday, November 12, 1988. This theorem, which is illustrated in figure 6a, is both inspired by and derived from Odom's theorem:

> Let there be three concentric circles. The radius of the middle circle is double that of the inner and half that of the outer circle. From any point on the inner circle draw a tangent line that makes a chord AC on the middle circle, and extend this chord from the point C until it reaches the point B on the outer circle. Then AC is cut in a golden section at B.

Because of this discovery, I no longer believe David Fowler's assertion that George Odom's construction is the simplest possible. For the three-circle construction seems to me to be a bit simpler even than Odom's. Except for the line that is cut in a golden section, it consists entirely of circles. Furthermore, rather than the six golden sections that can be constructed on Odom's diagram, there is no end to the number that can be constructed

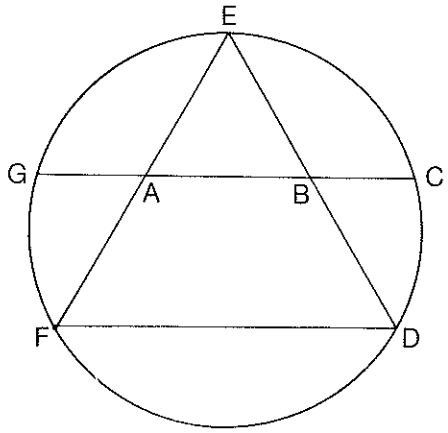

FIGURE 5. The proof of Odom's theorem by the crossed-chord theorem: Rectangle GB, BC=rectangle EB, BD [III.35], which implies that GB : EB : : BD : BC; but GB=AC, EB=AB, and BD=AB, so that AC : AB : : AB : BC, and AC is cut in a golden section at B.

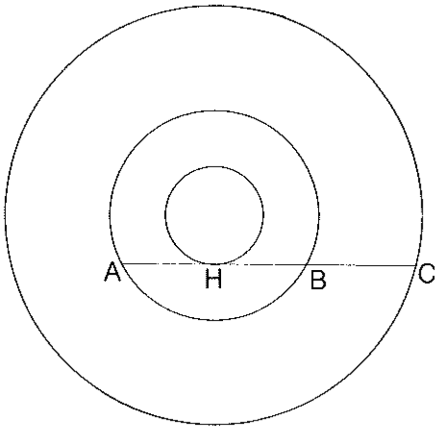

FIGURE 6a. The three-circle theorem.

The three circles are concentric.

The middle circle has double the radius of the inner circle and half the radius of the outer circle.

AC touches the inner circle at H.

AC is cut in a golden section at B.

on these circles. If one considers a sequence of circles in the plane, all concentric, each of which has a radius double that of the one immediately within it, then a tangent can be drawn to any one of the circles and golden sections can be imagined to appear on this diagram smaller, or larger, than any given size.

Neither Odom's theorem nor mine begins with a line that is to be cut in a golden section, but figures 6b and 6c and their accompanying explanations show how these theorems lead one to such a construction. Perhaps this construction is published for the first time here.

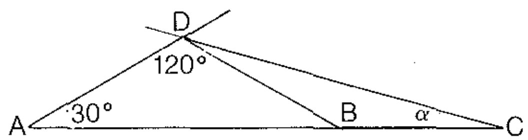

FIGURE 6b. To cut a given line in a golden section.

Construct angle CAD=30°, and angle ACD=α. Let α be the angle whose sine is ¼ (see figure 6c). Construct angle ADB=120°.

Then B cuts AC in a golden section.

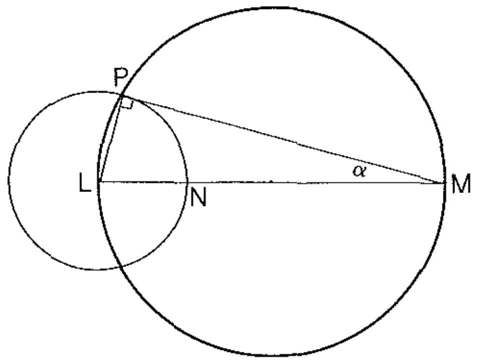

FIGURE 6c. To construct angle α for figure 6b.

Construct a circle with a given line LM as its diameter.

Let LN=¼LM, and construct a circle with LN as radius.

Let P be one of the points where the circles intersect.

Join PM. Then angle LMP=α, an angle whose sine=¼.

II. Morley's Theorem

It is impossible to trisect the sixty-degree angle of an equilateral triangle with straight lines and circles, or, to use the language of instruments, with straightedge and compass. Trisectors of an angle can be constructed, however, with the use of conic sections. On page 356 of *Geometrical Investigations* by John Pottage, he constructs a regular three-pointed star from the trisectors (see figure 7), and he asks his readers to show "that the star covers exactly two-fifths of the area of the triangle." Although Pottage does not mention the intersections DEF of the trisectors that are adjacent to each side of the triangle, they are indicated on figure 7. Because of the symmetry of the original equilateral triangle, it is to be expected that the three points DEF themselves form the vertices of a new, centered, inverted, equilateral triangle.

Next let us consider (see figure 8) a triangle for which each of the angles can be trisected with straightedge and compass: an isosceles right triangle.

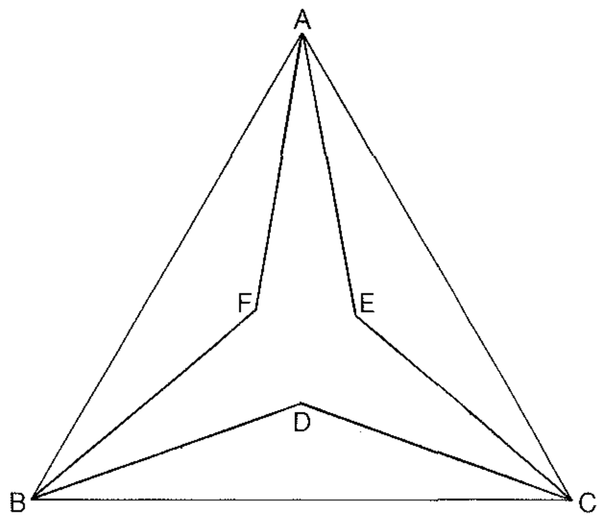

FIGURE 7. A three-pointed star made from the trisectors of angles A, B, and C.

The area of the star is two-fifths that of the triangle.

D, E, and F are the vertices of an equilateral triangle.

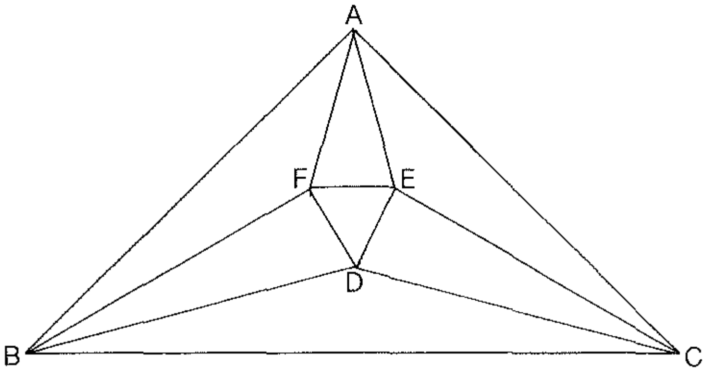

FIGURE 8. The trisectors of the angles of the right triangle ABC meet at points D, E, and F, which appear to be the vertices of an equilateral triangle.

Again we expect the trisectors to meet with their intersections forming the vertices of an inverted triangle, perhaps another isosceles right triangle. But figure 8 does not exhibit a right triangle. To the eye, it too seems to be equilateral.

Finally, figure 9 is a representation of the same kind of trisected figure now for a scalene triangle. Even here, the triangle DEF seems to be equilateral! As in the case of Odom's theorem, no one seems to have investigated such a configuration before the last hundred years. This time the discovery occurs at the very beginning of this century. Let us quote from the Biographical Notes[5] about Frank Morley, a President of the American Mathematical Society in 1919 and 1920:

> By about 1900 the following result due to Prof. Morley was well known to Cambridge mathematicians and others: "if the angles of any triangle be trisected, the triangle, formed by the meets of pairs of trisectors, each pair being adjacent to the same side, is equilateral." The first reference to it as "Morley's theorem," a term now in general use, seems to have been . . . in 1914.

In 1924, Frank Morley revealed how he found his theorem. Just as George Odom found his construction that takes place all in one plane while he was reflecting on a more complicated configuration, a solid figure; so did Morley find his elegant theorem that involves nothing but straight lines by considering a more complicated situation in which a higher order curve, a cardioid (see figure 10), touches the sides of a triangle. In 1909 the first

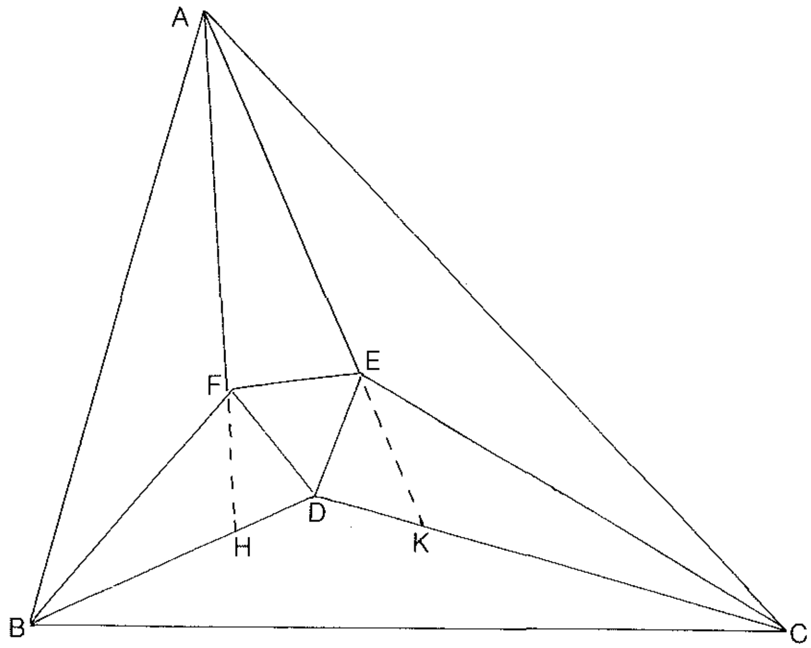

FIGURE 9. The trisectors of scalene triangle ABC meet at points D, E, and F, which again appear to be the vertices of an equilateral triangle.

The proof accompanying figure 11 determines the lines HF and KE.

elementary proofs were published in response to a challenge in the *Educational Times.* None of these proofs is quick, for it seems necessary to calculate the sizes of many angles. The proof that accompanies figure 11 is a ghostly one, by H. D. Grossman[6], in which the top part of the figure is never drawn and only comes into being at the last step of the proof. The motivation for this proof can be seen in figure 9, where each of the trisectors is extended. The whole effort is to determine lines HF and KE of that figure and to determine that they are the trisectors of the invisible summit angle.

What is the next step to take after considering Morley's theorem? Perhaps this: On page 98 of *Mathematical Gems,* Ross Honsberger asks his readers to

> show that Morley's theorem holds also in the case of the trisection of the *exterior* angles of a triangle. He has a solution on pages 163 and 164.

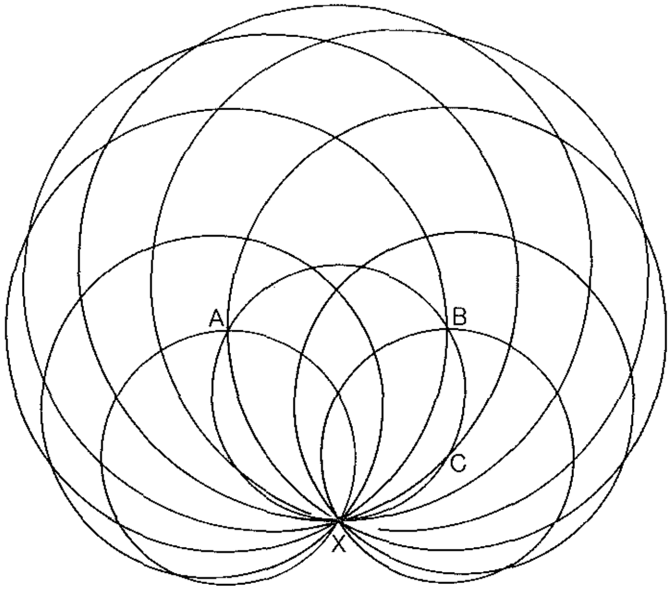

FIGURE 10. A Cardioid.

From any point X on the circle ABC, let A be the center and AX the radius of another circle. The cardioid is the envelope to these circles. The point X is called the *cusp*. Frank Morley discovered the theorem that bears his name by considering how a cardioid touches the sides of a triangle.

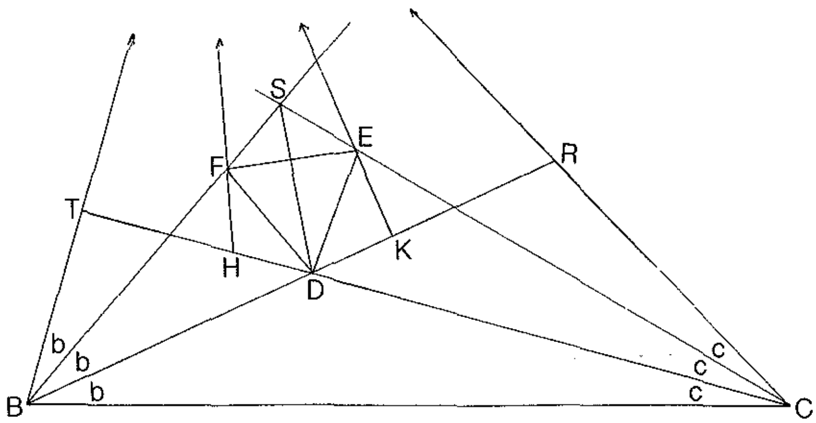

FIGURE 11. H. D. Grossman's ghostly figure for Morley's theorem.

Proof of Morley's theorem:

1. BC is the base of the triangle for which we shall prove Morley's theorem. The base angles are 3b and 3c. A is the invisible vertex at the summit, and the angle is 3a.
2. Let BF and BD trisect angle B, and let CE and CD trisect angle C.
3. Let BF and CE meet at S.
4. Construct angles SDF and SDE each equal to 30°.
5. D is the center of the inscribed circle of triangle SBC. Therefore DS bisects angle BSC.
6. Triangles FDS and EDS are congruent. FD=DE, and triangle FED is equilateral.
7. Angle EDC=60°+b, and angle FDB=60°+c.
8. Angle FDT=60°−b, and angle EDR=60°−c.
9. Construct angle DFH=60°−b, and angle DEK=60°−c.
10. Angle HFB=60°−c=a+b.
11. By Euclid's fifth postulate HF meets BT, at an angle=(a+b)−b=a. Similarly, EK meets CR at angle a.

The proof will be complete when it is demonstrated that the straight lines BT, HF, KE, and CR meet in a single point, which must be the vertex A of the triangle.

12. Draw FK, which bisects angle EKD.
13. By Euclid's fifth postulate, EK meets BT, and it meets it at angle a, and F is the center of the inscribed circle of the triangle with sides BT, BK, and KE. The bisector of the summit angle of that triangle divides the summit angle into two angles each equal to a; therefore it must either be parallel to HF or coincide with HF. And it must coincide with HF because F is the center of the inscribed circle, and that is where the angle bisectors of the triangle meet.
14. Similarly, in the triangle with sides FH, HC, and CR, the bisector of the summit angle coincides with EK.
15. Thus the undrawn angle at A is trisected by FH and EK, and the trisectors adjacent to each side of the triangle meet at points D, E, and F, which are the vertices of an equilateral triangle.

III. Viviani's Theorem

On page 22 of *Mathematical Gems,* Ross Honsberger does not consider *Viviani's Theorem* to be one of the outstanding theorems involving equilateral triangles. It is a mere "easy property" to serve his needs later. To use his own image of a *gem,* I believe that this theorem is a gem when it is placed in the proper setting, but Ross Honsberger did not choose to do so. I attempt to remedy that omission here. Much of the beauty of Viviani's theorem will be lost if it is even stated at the beginning of the discussion. It depends on a surprise. Let us delay our formulation of Viviani's theorem and pose a problem of finding a *minimum.*

> For any point in or on the boundary of a triangle, construct the perpendiculars to the triangle's sides. For which point is the sum of these perpendiculars a minimum?

To frame a conjecture for this problem, consider a scalene triangle as in figure 12, where calculations have been made at several points showing the sum of the distances to the sides. When we look at the calculations

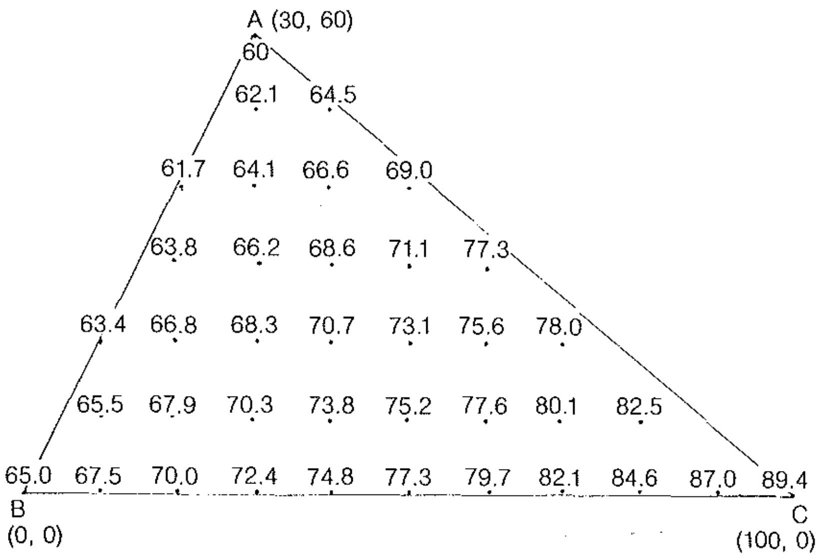

FIGURE 12. The minimum sum of the distances of perpendiculars to the sides of triangle ABC seems to be at the vertex of the greatest angle A.

given on that figure, a reasonable claim is that the minimum lies at the corner of the triangle with the largest angle. In that corner two of the three perpendiculars are unnecessary, and certainly the point at the largest corner is closer to its opposite side than is the case at either of the other corners. We shall prove at the end of this section that this conjecture is correct. But first, it is easy to build on the conjecture for an isosceles triangle in which the equal base angles are each larger than the summit angle, by claiming that either of the vertices at the base serves as a minimum. This claim is also correct. Finally, consider an equilateral triangle. It seems clear that there are three minimum points—namely, at the three corners or vertices—but it is *not* clear. Unlike the other claims, this one is false! The search for a minimum here is misguided. Instead Viviani's theorem holds:

> For any point in or on the boundary of an equilateral triangle, the sum of the perpendiculars to the sides of the triangle is always equal to the height of the triangle.

The beauty of this theorem, then, depends, at least in part, on its surprising character. A proof of Viviani's theorem is given accompanying figure 13. It depends on a theorem that is not in the *Elements*, and could not

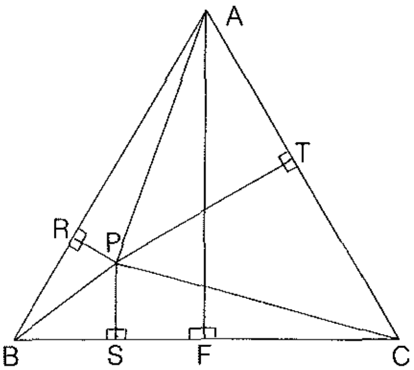

FIGURE 13. Viviani's theorem.

Triangle ABC=triangles APB, BPC, and CPA.

½BC•AF=½AB•PR+½BC•PS+½CA•PT.

But both AB and CA are equal to BC, so that

½BC•AF=½BC•PR+½BC•PS+½BC•PT.

Therefore AF=PR+PS+PT.

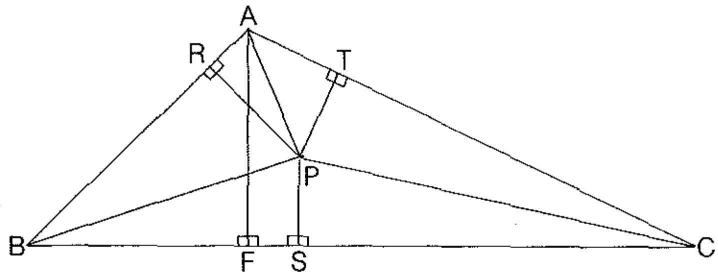

FIGURE 14. The sum of the perpendiculars is a minimum at the vertex with the largest angle A.

Triangle ABC=triangles APB, BPC, and CPA.

$\frac{1}{2}BC \cdot AF = \frac{1}{2}AB \cdot PR + \frac{1}{2}BC \cdot PS + \frac{1}{2}CA \cdot PT.$

But $BC > AB$, and $BC > CA$.

Therefore $\frac{1}{2}BC \cdot AF < \frac{1}{2}BC \cdot PR + \frac{1}{2}BC \cdot PS + \frac{1}{2}BC \cdot PT$,

and $AF < PR + PS + PT$.

be there, that the area of a triangle equals half the base times the height. Readers are encouraged to construct a proof in the manner of Euclid.

To conclude this section, accompanying figure 14 is the proof that I promised to give, that for scalene triangles the minimum point for the sum of the perpendiculars is at the vertex of the largest angle. (This is problem 17 in *Maxima and Minima Without Calculus* by I. Niven, who gives this solution on pages 279 and 280.)

IV. Napoleon's Theorem

In Ross Honsberger's chapter on Equilateral Triangles on page 34 of *Mathematical Gems*, we read:

> Historically, the following theorem is known as Napoleon's theorem, although it is very doubtful that Napoleon was well enough versed in geometry to have discovered and proved it himself.

Whatever its origin, Napoleon's theorem is wonderful:

> Consider any triangle with equilateral triangles drawn outward on each of the three sides, as in figure 15. Napoleon's theorem states that the centers of these three triangles are themselves the vertices of an equilateral triangle.

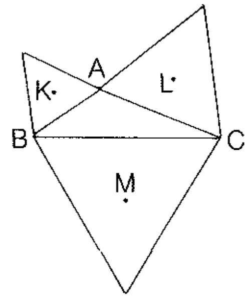

FIGURE 15. Napoleon's theorem.

The points K, L, and M are the centers of three equilateral triangles drawn outwardly on triangle ABC. To prove that K, L, and M are the vertices of an equilateral triangle.

What is perhaps surprising here is that no matter now unequal the sides of the original triangles, a perfect equilateral triangle will still be formed. The advantage of placing equilateral triangles on the sides is that there is no need to worry about which center we have in mind: the center of gravity, the center of the inscribed circle, the center of the circumscribed circle, the orthocenter (where the three heights meet), or some more exotic center. The extreme symmetry of the equilateral triangle guarantees that all of these centers merge into a single point: *the* center.

An excellent setting for Napoleon's theorem is another minimum problem that was posed by Fermat to Torricelli:

> Find a point in an acute-angled triangle so that the sum of the distances to the three corners is a minimum (see figure 16).

This problem is now called the airport problem:

> Where should we build an airport so that the sum of the distances to three cities is a minimum?

In figure 17, we have added a construction to figure 16 in which triangle ACN is rotated 60 degrees about point A to position AED. Moreover, we have joined points C and D as well as N and E with straight lines. In that process, two equilateral triangles have been constructed: AEN and ADC. Consequently, the sum that we wish to minimize, BN+CN+AN, can be replaced by the equal path BN+NE+ED. In the same figure 17, the letter

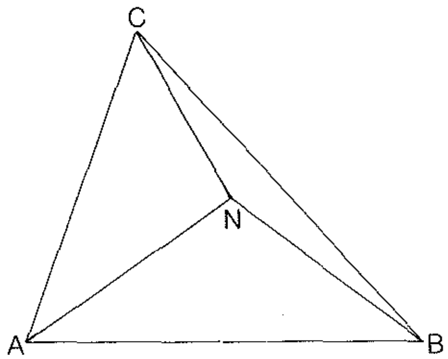

FIGURE 16. Fermat's problem (the airport problem).

In an acute-angled triangle find the Fermat point F such that the sum FA+FB+FC is a minimum. The point N is a non-Fermat point, since there are smaller sums than NA+NB+NC.

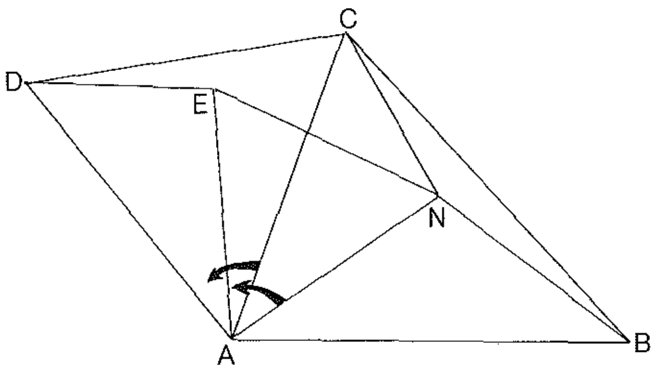

FIGURE 17. A path is found equal in length to BN+NA+NC.

Rotate triangle ACN 60° about A. Connect CD and NE.

Triangles ACD and AEN are equilateral.

Since NA=NE and NC=ED, we have BN+NA+NC equal to path BN+NE+ED.

This path will be a minimum when the three segments BN, NE, and ED lie in a straight line. Such a path is drawn in figure 18.

N stands for a Non-Fermat point because the path is not a minimum. The excellence of this method of proof is that we shall know at once when we have F, a Fermat point, as in figure 18, for the path will be minimized when F is chosen so that BF, FE, and ED all lie in one straight line. Underneath figure 18 is a calculation that shows that the Fermat point is the one in the triangle that makes all three angles AFB, BFC, and CFA equal to 120 degrees. Figure 19 shows the first of two constructions that enable us to locate the Fermat point. Because the opposite angles ADC and AFC of quadrilateral AFCD sum to two right angles, the circle about equilateral triangle ABC passes through the Fermat point F. Thus we have the first of our two constructions for F:

> To find the Fermat point for any acute-angled triangle ABC, construct an equilateral triangle outwardly on one of the sides AC. Then the Fermat point is the intersection inside the triangle of the circumcircle of triangle ABC and the straight line BD.

There is another construction for the Fermat point illustrated in figure 20. Here we have equilateral triangles ADC, AOB, and BHC constructed outwardly on each side of the triangle. For the same reason that the Fermat

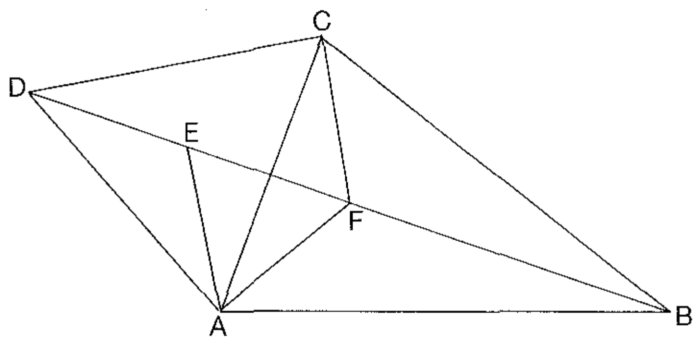

FIGURE 18. The Fermat point F solves the airport problem.
The three angles at F are each equal to 120°:
Angle AFB = 180° − angle AFE = 120°.
Angle AFC = angle AED = 180° − angle AFE = 120°.
Therefore angle CFB must also be equal to 120°.

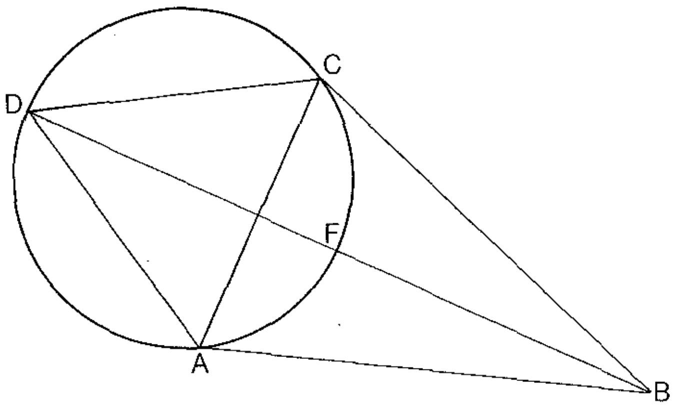

FIGURE 19. First construction of a Fermat point.

By III.22 the opposite angles of the undrawn quadrilateral ADCF are equal to 180°. Angle ADC=60°, so that angle CFA=120°. Consequently F satisfies both conditions for a Fermat point: F lies on BD, and angle AFC=120°.

point lies on BD, it will also lie on AH and CO. Not only do we have this second construction for a Fermat point, but we are also all set up for Napoleon's theorem, in which we must show that the centers of the three equilateral triangles are necessarily the vertices of an equilateral triangle. Consider the circles about the two upper equilateral triangles in Figure 21. CF is a chord of both circles. By the first proposition of Book III of the *Elements*, the perpendicular bisector of CF must pass through the centers K and L. Similarly, in figure 22 the perpendicular bisector of AF passes through K and M, and of BF through L and M. Since the three chords FC, FA, and FB make angles of 120 degrees with each other, a simple calculation shows that the angles of triangle KLM are each equal to 60 degrees. This is enough to determine that triangle KLM is equilateral, and our proof of Napoleon's theorem is complete.

I close this section with two questions:

1. Is Napoleon's theorem still true if the triangles are drawn inwardly?

2. On any triangle draw similar triangles outwardly on the three sides. For which kind of center for the triangles will the three centers form the vertices of a triangle that is similar to the other three?

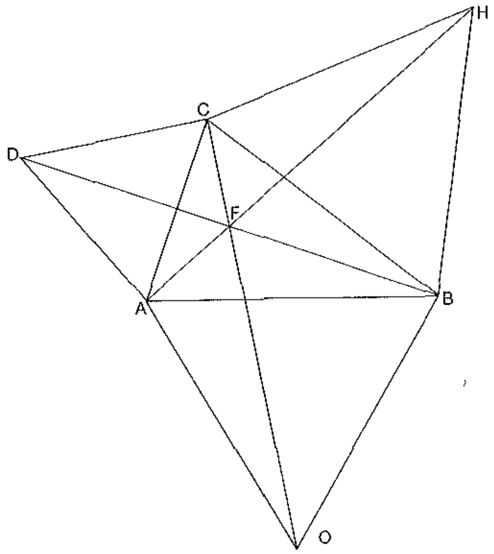

FIGURE 20. Second construction of a Fermat point.

Just as the Fermat point must lie on BD, it must also lie on both AH and CO. Than we can construct the Fermat point as the intersection of any two, or all three, of the lines BD, AH, and CO.

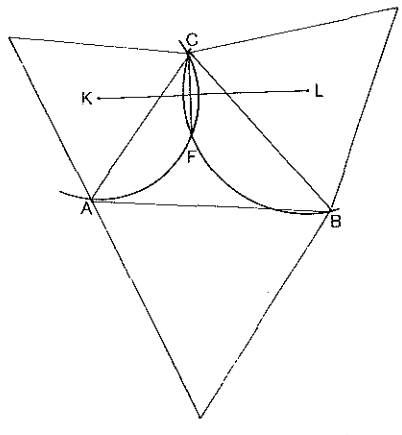

FIGURE 21. The beginning of a proof of Napoleon's theorem.

Again F is the Fermat point. By III.1, the perpendicular bisector to the chord CF must pass through the center's K and L of both circles.

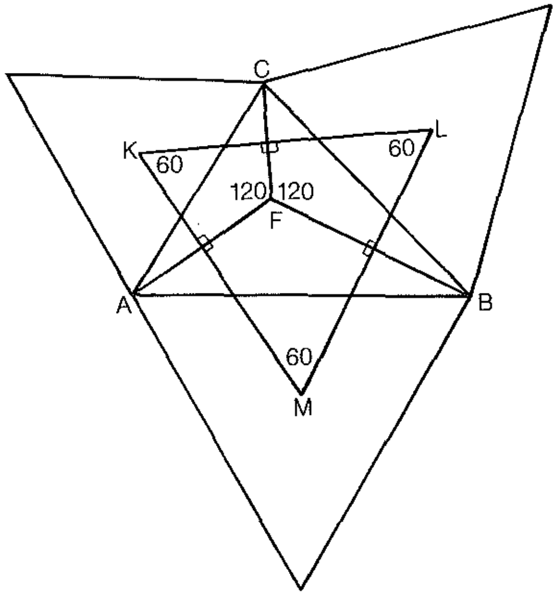

FIGURE 22. Conclusion of Napoleon's theorem.

By III.22, the angles at K, L, and M must each be equal to 60°, and triangle KLM is equilateral.

V. Triangles of Maximum Area

As an appetizer:

For all triangles inscribed in a given circle, which has the greatest area?

The delightful method of solving this problem that is presented here comes from pages 19 and 20 of *The Enjoyment of Mathematics* by Rademacher and Toeplitz:

This proof comes in two parts. We show that of two triangles inscribed in a circle

1. An equilateral triangle has a greater area than any triangle that has only one side equal to an equilateral triangle.
2. A triangle with one side equal to an equilateral triangle has a greater area than a triangle with none equal to an equilateral triangle.

Let triangle ABC be inscribed in a circle with one side AC equal to an inscribed equilateral triangle oriented with AC as its horizontal base—figure 23. If an equilateral triangle AHC is inscribed on the same base,

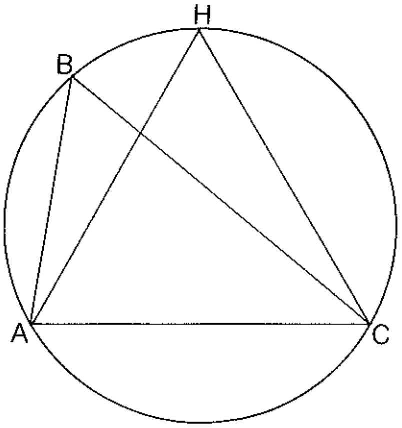

FIGURE 23. The area of an inscribed equilateral triangle is greater than any other inscribed triangle on the same base.

then as everyone knows the equilateral triangle will rise to the highest point H of the circle, and since of two triangles on the same base, the one with the greater height has the greater area, the equilateral triangle has a greater area than the scalene triangle with one arc equal to 120 degrees.

The proof will be complete when it is shown that of inscribed triangles, the triangle with one side equal to an equilateral triangle is always greater than one with no sides equal to an equilateral triangle. Such a triangle must have at least one side—say AB—cutting off less than a third of the circumference, and at least one side—say BC—greater than a third of the circumference; it does not matter whether the third arc is greater or less than 120 degrees. Place AC as the horizontal base, as in figure 24. Now, let arc CB* = AB, so that triangle ACB* can be considered the mirror image of triangle CAB about the vertical diameter. Finally, if AH is the side of an inscribed equilateral triangle, then, since AH is greater than AB and less than AB*, H must lie in the arc BB* across the top of the circle, and H will be higher than B and B*. This means that the triangle AHC, which is taller and on the same base, is necessarily of greater area than ABC. Consequently, any triangle with one side cutting off one-third of the circumference of the circle has a greater area than a triangle that does not have such a side, and the proof is complete.

The last theorem was the appetizer. Here is the main course:

> Of all triangles with the same perimeter, the equilateral triangle has the greatest area.

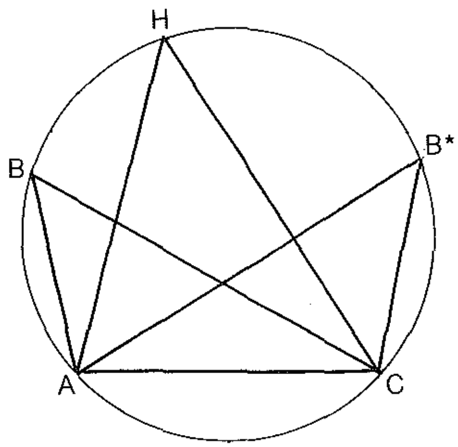

FIGURE 24. Triangle AHC, which has one side AH equal to that of an inscribed equilateral triangle, is greater than triangle ABC, which has no such side. Triangle AB*C is the mirror image of triangle ABC when the vertical line through the center serves as the mirror.

I know an algebraic proof of this theorem that I learned from pages 47 and 48 of *Maxima and Minima Without Calculus* by Niven. While away from my library in the summer of 1988, I was able to devise a two-part proof that seems to me rather elegant. When I returned to my books, I learned that Ivan Niven himself suggested the first part of the proof that I had found:

1. On a given base and for a given perimeter, the isosceles triangle has the greatest area.

As in figure 25, let ST be the base, and let ST+TU+US be the given perimeter. Then the locus of all triangles on the base ST lies on an ellipse. Moreoever, the point U* where the triangle is isosceles is located at the highest point of the ellipse. Thus the first part is clear: Again, since the area of a triangle is equal to half the base times the height, the isosceles triangle has a greater area than any triangle on the same base with sides that equal its sides in length.

2. To show how the equilateral triangle dominates in size any isosceles triangle with the same perimeter, let us take an example that presents a

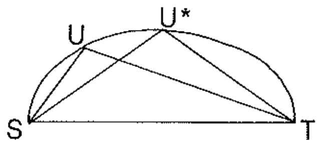

FIGURE 25. The semi-ellipse is the locus of all points U such that SU+UT is constant and greater that ST.

The isosceles triangle SU*T has a greater area than that of any other triangle inscribed in the semi-ellipse.

method that will work for every triangle. Begin with a scalene triangle with sides of length {7, 10, 5}. From the last theorem this triangle has a smaller area than the triangle {6, 10, 6}. The trick now is to let the base be 6 rather than 10, and so we write the same triangle {10, 6, 6}. Then the same averaging method of finding a new isosceles triangle on this base yields the triangle with larger area: {8, 6, 8}. Notice how the triangles are becoming closer in shape to an equilateral triangle. The next steps yield {7, 8, 7}, the next {7.5, 7, 7.5}, and so on *in infinitum*. As Isaac Newton would say, this sequence of triangles of ever-increasing area is *ultimately equal*, or is equal in the *limit*, to the equilateral triangle. All that is needed to make the proof rigorous—but I will not do so here—is to show that the ever-increasing sequence of triangles differs from its limit, the equilateral triangle, by less than any pre-assigned difference D.

I was very pleased with my discovery, and I wondered if anyone had ever followed the same line of reasoning. I found it all carefully worked out in Nicholas Kazarinoff's excellent book called *Geometric Inequalities*. Following his presentation, on page 41, which he attributes to Simon Lhuilier, Kazarinoff presents what he calls a "clever geometric construction ... due to Jacob Steiner [that] neatly avoided the method of successive approximations employed by Lhuilier." However, Lhuilier's method is charming, and is in fact a fine theorem with which to teach the theory of limits.

The next question

> For all plane figures with a given perimeter, which one contains the greatest area?

is addressed as the sole subject matter in chapter 22 of *The Enjoyment of Mathematics* by Rademacher and Toeplitz.

VI. Concluding Remark

In an involved connected account—Euclid's *Elements* or Newton's *Principia*—a large measure of the beauty that one finds comes from the more or less systematic presentation. I have tried to illustrate in this article that there is another kind of beauty that one can appreciate: particular theorems that, in order to delight, need not be presented in a long chain of argumentation. No doubt any of the sections here can be extended, and I have made some suggestions about how to continue beyond what is presented here. My claim is, however, that these theorems and proofs can be appreciated just as they stand. Each is a good in itself. In the bibliography given below such goods abound.

VII. Footnotes

1. Vol. 90, p. 482.
2. Vol. VII (1987), pp. 201–10.
3. Vol. 93, p. 572.
4. *A Mathematical History of Division in Extreme and Mean Ratio* (Waterloo, Ont.: Laurier).
5. R. C. Archibald: *A Semicentennial History of the American Mathematical Society,* Vol. I (Menasha, WI: The Collegiate Press, 1938).
6. *The American Mathematical Monthly,* Vol. 50 (1943), p. 552.

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Autopsy

Melinda Rooney

The first time Lucy went to see her father take a horse apart it was near Halloween. She'd been asking to go for weeks. She was sitting on newspapers in the middle of the kitchen with a pumpkin between her legs, scrubbing it with water and a stiff brush. He came in and swung a chair around and sat on it backwards. She looked up at him. When he didn't say anything she looked back down and picked up a black magic marker and drew a wobbly line around the pumpkin's stem for the knife to follow.

"Lucy?"

"What." She didn't look up. The long blade of the butcher knife squeaked in the pumpkin.

"Do you want to come watch tomorrow while I post a horse?"

She looked up, leaving the knife standing handle-up in the pumpkin. "Really?"

"I'm asking you if you want to come with me. It'll be a whole morning, a Saturday. Do you really want to give up a whole Saturday morning?"

"Yeah," Lucy said. There was a silence.

"How come?" her father said.

"I don't know," Lucy said. "To see what you do. I never get to see what you do." I want to see a dead thing, Lucy thought.

"Well, okay. You'll have to be up early in the morning. I need to be there by six-thirty."

"Okay."

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"Are you supposed to be using that knife in here all by yourself?"

"Yeah."

"Lucy?"

"What?"

"You really want to go," he said.

She looked down and pulled the knife handle back with her finger then released it and watched it vibrate, embedded in the pumpkin. "Yeah," Lucy said. "I want to see."

"It's not very pleasant," he said.

"I know," she said, grabbing the stem of the pumpkin and pulling the top off. She held it above the newspapers, pulp and seeds hanging like sticky hair, then dropped it and stuck her hand in the hole and closed it in a slippery fist of thready pulp. Warm air rose from it.

"I know," she said again, leaning down and speaking into the pumpkin. Her voice had a thick echo. "I just want to see how you do it."

"Okay," her father said. He stood suddenly and said "Be careful with that," and walked away.

When Lucy was ready for bed her mother sat her on the edge of the bed and looked at her forehead and said "Now stay out of your father's way tomorrow. This is his job. He doesn't have time for all your questions the way he does when he's at home." She finally looked her directly in the eyes. "All right?"

Lucy nodded.

"All right," she continued. "Just save them all up for when you get home, and he can answer them then. All right?"

"Okay."

"Okay," said her mother. "All right," she said again, leaning stiffly over to kiss her.

Lucy arranged her stuffed animals around her body in a tight embrace. There was a plush tiger that had belonged to her dead aunt, fixed in a lying-down position with a pink nose and plastic whiskers like fishing line. There was a hinged bear, stiff and stuffed with straw, with prickly fur and a roar box that mooed when you tilted him. There was a St. Bernard with patchy fur and one shredding cardboard eye. Lucy had seen him lying by the side of the road and made her mother stop the car so she could run back to get him. He'd been lying on his back, one ear thrown out above his head. His coat was clogged with gravel and old rain. He was clean now, but he still smelled like road. There was a grey felt snake six feet long.

When Lucy was sleepy she would feel the bed jump and wiggle, then settle into a rising and falling like it was travelling across water and her animals would sway and murmur with the movement and then it was the next morning but tonight she wasn't sleepy. The bed sat still as a stone and her animals were stiff and silent.

Lucy did everything her father did. She followed him everywhere. When he plowed a garden she had marigold seeds in styrofoam cups on her windowsill, or beans, sprouting in little white curves. When he started writing books she'd begged for a toy typewriter. She'd sit on the toilet seat and watch him shave, then once took a razor blade from its waxy white paper and drew it across her cheek, laying it so neatly open it took almost five seconds to start bleeding.

Lucy's father was sad the way Lucy was sometimes sad, the way she was sad at night. It was worst when animals died. And animals died a lot where they lived, in a country house on a high-speed road. He would sit in a chair and stare in front of him when kittens died, or dogs, or the little ducks or birds Lucy brought home and fed sugar water from soaked Q-Tips. They always died and he would sit and watch them and he would tell Lucy it was nature and that was the way things lived and died but once their eyes dropped closed or their heads sagged against torn-up towels in their cardboard boxes he would have to leave the room and he could barely speak for days.

The first time this happened that Lucy really noticed it was when one of their cats had a kitten that was brain damaged and it cried from the time it came out of her mother to the moment she died, almost a day later. The mother didn't know what to do. She would curl herself around it then jump up and walk away. Lucy's father put the whole litter into the wagon of his tractor and sat with them, drinking cold coffee. All the kitten could do was lie still and cry. He sat with them for an afternoon and when she finally died he took her out back in the palm of his hand and buried her. He dug the grave with a spoon. He came into the kitchen and sat Lucy down at the table and explained how her brain hadn't got put together the right way and so she had died. "Nature takes care of things like this," he said, "and death is sort of a relief," and he got up and left the room.

He came home one day and told Lucy's mother he'd found a horse that had been struck by lightning in a field and Lucy went upstairs and made beds for her animals out of shoeboxes and lined them up like hospital cots.

She asked her father later what he did with the horse and tried to imagine its insides. He had to be all black like the inside of a bag of charcoal, his blood hard and red like clay. He said they'd cut it open to make sure that's how it died. That was when she started wanting to see an autopsy.

Lucy woke up in the cold dark and saw her father sitting in a little chair by the window.

"Is it time to go?" Neither Lucy nor her animals had moved in her sleep.

"Almost," he said, looking out the window.

"What time is it?"

"Quarter to five."

"It's still dark," Lucy said.

"I know."

There was a noise in the air. Her father stood up and pushed the chair under its little desk. It was a wooden desk with a white metal top scattered with plastic letter magnets. Lucy hardly ever played with it anymore because she couldn't fit under it without lifting it off the floor with her knees.

Her father looked at her, startled. "What?" he said.

"I didn't say anything."

"Oh. I'm sorry. I'm tired."

"Oh."

"We have to leave in about a half-hour," he said, standing up and walking to the bedroom door. "So up."

They had to walk a long way to the garage. Dull white frost sat in the grass and Lucy wore her father's sweater, tears standing in her eyes from the early cold. It hung to her knees. She bunched the sleeves in both fists and smelled her father all around her. There were buckets and a length of hose in the bed of the truck and the floor of the cab was covered with fine gravel from other men's boots. Thick heat filled the cab as they drove and Lucy started to talk.

"What's wrong with this horse?"

"A nervous system thing. Convulsions."

"Oh." There was a pause. "Can't you fix it?"

"Not really. I'm not even sure we'll be able to see anything once we open it up. This only shows up in tissue samples."

"What only shows up?"

"The problem. What's wrong."

"Germs?"

"Yeah," her father said, "Well, sort of."

"How can you find little germs in all that horse?"

"Microscopes."

The sun was up. Lucy remembered a movie her father had in the home movies box that was a filly running around a paddock with men circling around her. She had a funny, jerky run and her legs would fly out at odd angles and her head would toss back as though she were on strings. When she stood still she looked fine but she could never stand completely still.

They were almost to the lab when Lucy said "How can you fix what's wrong if you have to kill him to find out what's wrong?"

There was a long silence as they pulled through a humming metal gate. "So that maybe we'll be able to fix it next time," he said, pulling around a curve and letting the wheel slide through his fingers.

"Oh," Lucy said.

The building with the autopsy room in it was at the end of a long asphalt drive spotted with flattened dung and wet hay. Four men were huddled together in front of giant motor-driven doors. The doors were latched shut and bound with a thick chain like the doors to a big freezer. Lucy's father jumped out of the truck and half-ran, half-walked over to the men and they talked quietly, their words puffs in the cold air. Mist rose from the grass. The men turned and walked off in different directions and Lucy's father came back to the truck and opened the door.

"Okay, hop out," he said and she slid down from the high seat. He kicked arcs in the gravel as he thought a minute.

"Okay," he finally said. "I'll take you in and get you settled. It'll be a few minutes before you see me. I have to get dressed and talk to these fellows and get everything set. Will you be okay for a few minutes by yourself?" Lucy nodded, suddenly frightened.

"You can't touch anything," he said. They walked over to the giant doors and he unlocked the chain lock with a silver key and pushed a button. Somewhere a motor jumped and sighed and the doors rattled open on their greasy tracks. He walked Lucy over to a long counter at the other side of the room where he lifted her up so that she was sitting next to a deep sink with a thin curving faucet.

"I'll be back in a minute. I'm going to go find you something to play with," he said, and disappeared through a door. Its square glass window had a wire net running through it.

The room was all gray cement and stainless steel; the floor had a silver drain in it for hosing away mess and the counter Lucy sat on was lined with glass jars of old white twisted guts soaking in formaldehyde. There was a table with an electric saw in it for cutting bone.

There was a rusty hook hanging from a chain in the ceiling, and a steel table with a groove down the middle. Lucy looked down at her feet, stuck the toe of her sneaker into a drawer handle and tried to pull it open but it was locked. There was a long yellow bone behind the faucet handles.

Lucy's father came back through the door with both hands full. He stopped at the counter and lined up what he'd brought. The best were syringes, minus needles, wrapped in thick plastic.

"You can play with these in the sink if you don't splash too much," he said, handing them to her. There were a few glass slides with little pink explosions of stained tissue and a magnifying glass with a heavy black handle. There were three or four heavy silver cylinders that her father said were cow magnets. He told her they put the magnets in cow stomachs and they would collect little metal things like nails or staples they picked up as they grazed so their stomachs wouldn't get cut.

"Do you think this will keep you occupied for awhile?"

"Yeah, definitely."

"Okay, I'm going to get dressed. I'll be back in a couple of minutes."

Lucy sat on the counter, banging her heels against the metal drawers. She picked up a cow magnet and walked around the room, touching it to metal things and pulling it off again. She went back to the sink and ran it half full of water and grew absorbed with the syringes, drawing water into the narrow plastic barrels and shooting it against the side of the sink. It made a ringing sound.

When Lucy turned around there were three men in the room who were looking at her, startled.

"My dad's getting dressed," she said. They were wearing baggy green clothes and paper slippers over their shoes that looked like the white paper frills on Thanksgiving turkeys. Her father came in dressed in the same way except he wore black rubber boots with thick red soles. Lucy emptied the sink then jumped to the counter and hooked her toe in a drawer pull. Her father sharpened a knife.

The big freezer doors slid open again and two men in green with parkas on walked in with a white horse who jerked and wobbled like a mechanical toy. Even as she stood still some part of her was moving, twitching the wrong way and she stamped as Lucy's father walked to her carrying a syringe. Lucy thought suddenly of a toy she'd taken from her dentist's treasure chest years before—a hinged donkey that collapsed when you pushed a button under its little stand—and her father pinched a fold of skin at the base of the horse's neck and slid the needle in and after only a few seconds she sank to her knees and died on the tile floor, as though she'd suddenly been overcome by sleep. He stepped back and away as she stretched out on her side.

Lucy's hands sat cold in her lap while the giant iron hook was lowered from the ceiling and two men bound the mare's legs together with rope. They hooked the loop in the rope over the hanging hook and a motor whined loudly as the hook rose again, pulling her up and off the ground. The hook followed a track in the ceiling over to the big steel table and they lowered the horse onto it, her back fitting neatly into the groove.

They released her legs and unwound the rope and a man came in with a hose and sprayed down the floor. Her white head hung upside down off the end of the table and her tail brushed the floor, its ends dampening. Lucy's father stood so she couldn't see his hands but by the way his back tensed she knew he was cutting her open and there was a sound like wet fabric tearing. Steam rose from her body and she spilled apart on the table and onto the floor.

The guts smelled like wet cardboard boxes and were more colors than Lucy had expected—green, blue, yellow. Her father slid most of the horse out onto the floor like he was digging through a pile of laundry. No one was talking. She looked again at the electric saw: the words "Butcher Boy" were spelled out in red and silver letters opposite the thick blade.

"Dad?" Lucy said, sliding off the counter and standing with both hands fixed in drawer pulls. She stepped forward but her hands stayed cold and locked on the handles.

"Dad?" She felt a thick pain under one eyebrow where she'd fallen once and hit the corner of a table. "Can I see what you're doing?"

With blood on them she could suddenly see how white and thick his arms were and when he turned to face her she saw a gash of brown blood by his ear and under one eye. His mouth was fixed in a line when he said "*What*, Lucy," and she suddenly remembered when she'd gone with her mother to see him play ice hockey once and he had been standing in a little net cage wearing a white plastic mask and her mother had pointed and said, "Look! There's your father!" and she'd looked at the mask with its slanted black holes and screamed "That's not my father!" and a man on the bleacher in front of her jumped and tossed his popcorn in a yellow shower. She'd screamed until her mother picked her up and carried her to the car. She'd fallen asleep on the cold seat and refused to go into the house all night.

"Lucy," he said now. "*What*." She felt the drawer pulls making ridges in her hands.

"You have blood on your face," she said.

He looked at her.

"I want to go back to the car," she said.

"Lucy," he said, "I'm busy. Sit down." He turned back to the guts.

"Dad!" she shouted.

"Hey, John, I'll take her back to the car," one of the men said.

"No," he said, "just . . . " He fixed the knife handle up in the horse's belly. He turned to Lucy.

"Lucy," he said. "Sit down. You came to see this. Now sit *down.*"

They stared at each other for a long minute that smelled of blood and formaldehyde and some dead, rotting thing. Then she jumped back on the counter and held a cow magnet until it grew hot in her hand and her eyes had cleared and her father had emptied the horse.

When it was over he walked out of the room and the men hosed what was left down the drain or out the door to an open dumpster. All that was left of the horse was a white shell, the ribs standing stiffly like hands reaching up, waiting to be given something.

Lucy slid off the counter and looked at the slides with the magnifying glass, then looked up to see one of the men standing next to her. He had black hair cut so short the skin of his head looked blue and his arms were raw with harsh soap and goosebumps. He had black plastic glasses on with a string attached and he offered Lucy a piece of gum.

"You okay?" he said.

"Thanks."

He opened his mouth to say something, then paused, cleared his throat, and looked away before he finally said "What do you think of all this?"

"I don't know. It's okay. It's interesting." Her voice shook.

He looked at her for a moment. He walked away, then stopped and turned around. "Do you want me to take you in to see your dad?" Lucy looked at him for a long minute, backed against the counter.

"I guess," she said, not moving. "Or I could just wait for him here."

"Come on," he said, walking back over to her and reaching out his hand. "I'll take you to him."

She went reluctantly, feeling the pull of the man's arm in her shoulder. He took her through a heavy wood door into a room full of lockers and loud talking and cigarette smoke. Her father was at a sink, soaping his hands and scrubbing between his fingers with a little brush. He looked over at her. She sat down on a bench and the man who'd brought her in walked away without a sound. They stared at each other.

"What do you have in your mouth?" he finally said.

"Gum." She paused. "That man gave it to me. He thought I was scared."

There was a silence.

"Give me one more minute," he said, and rinsed his hands and arms and disappeared into the lockers. He came out a few minutes later in his regular clothes. He didn't even pause in front of her but only said "Ready?" and took her wrist and walked back out into the autopsy room. He walked to the counter and gathered up the syringes and magnets and gave Lucy the slides to carry. The man who'd given her the gum was coiling up the hose.

Lucy's father smoked a cigarette and the ash grew long and dropped off as he drove.

"Well?" he finally said.

"What?"

"What do you think?"

"I'm not sure."

"Was it what you expected?"

"I'm not sure."

"We couldn't see a thing," he said, rolling the window down an inch and thumbing the glowing butt out the window. "We'll have to wait for the tissue samples."

"Oh." Lucy looked out the window.

"Do you want to know what I found?"

"I thought you said you couldn't see anything."

There was a long silence. "Well, we won't know for sure until the tissue comes back," he said, almost to himself, then, his voice higher and a little afraid, "It's, it's kind of like when you carve your pumpkins, and you find one strange seed in the middle of all the regular ones. You know what I mean?"

"I guess."

It was quiet the rest of the way home. Right before they pulled into the driveway he slowed down, as though he were going to pull over, and looked at her. "Lucy?"

She moved suddenly back against the door, feeling the arm rest in her back as he pulled the truck onto the shoulder and stopped. She saw his face change and he reached out to her and took the back of her neck gently in his warm hand.

"Oh, Lucy," he said, his voice small.

"What?"

There was a long silence. He sighed and took a knot of her hair in his hand and forced brightness into his voice.

"Don't you . . . don't you want to ask me any questions?" His thumb was rough over the pain in her eyebrow. He smoothed it over and over.

Lucy said "No, not really," because she couldn't think of anything else to say. Her chest was full of hurt.

He sighed and said "Okay. Maybe some other time then, right?" He pulled the truck into the driveway in a whisper of gravel. "Okay?"

She looked at him for a long moment and he looked at her and she just said "Yeah, okay" and got out of the truck and walked into the house.

Petrella's Blood

Leo Pickens

Zia Pina sat at the hearth stirring beans boiling in a pot over the fire when Bob finally came downstairs for breakfast.

"Sleepyhead!"

"Easy," Bob said. "I'm on vacation."

"Did you sleep well?" Zia Pina asked. "You weren't too cold?"

"No."

"Sure?" She regarded her distant cousin carefully.

"I'm sure," he said.

She frowned. "Tonight we will give you another blanket."

Zia Pina rose slowly. The old widow was barely five feet tall, but so fat that she needed a small stool to sit at the dinner table. She could then push her bulk underneath the table top and reach her food. "What legs," she muttered. "What legs. The spirit still works fine. It's just these legs that don't." She opened a cupboard and took down a coffee pot.

Bob took the pot from her hands. "Sit down," he told her. "In America, men know how to make coffee. Understand?"

Zia Pina hesitated, puzzled. "No!" she said finally.

She grabbed the coffee pot, and as she did so Salvatore entered the kitchen. He was tall, thin, and worn. Still handsome, his close-clipped mustache gave him a certain dignity, even though his clothes were dirty and ill-fitting, and his shoes, without laces, had holes at the seams.

"My God! What are you doing?" he asked Zia Pina. "Why are you fighting with our guest?"

Leo Pickens, a graduate of St. John's College, Annapolis, is Director of Athletics at the college.

"I'm making the young man some coffee. What's it to you?"

Salvatore put an arm around her shoulder. He drew back her black scarf. "Look," he said to Bob, and he pulled gently at her hair. "Look at this old woman. It's snowed in her hair!"

"Ahhh . . ." Zia Pina lifted a thick arm and cuffed him.

"This old woman never dies! I'd give a million lire to anyone who could kill her. But it's impossible. She'll outlast us all!"

Zia Pina's heavy body shook with laughter. A ridge of gum appeared where her upper teeth once were. "What kind of nephew says such things?" she said. "What kind of nephew?"

"So you think you can make him some coffee?"

"But of course."

"But you don't know how to make coffee."

"*Madonna*," she said. "You think that because I'm old I can't do anything?"

"Well," Salvatore said, grinning, "old bones do make the best soup."

After his breakfast, Bob followed Salvatore outside. The morning was cool and softly radiant. Pasquale, Salvatore's brother-in-law, sat on a low table next to a fire burning under a barrel of water. He was sharpening a pair of long knives. Pasquale was small and stooped, with sunken cheeks. Bits of tobacco from his handrolled cigarettes clung to the corners of his mouth. Old as he appeared, Pasquale's movements were still spry and unlabored.

Pasquale greeted Bob with something he could not understand. Pasquale's accent was thicker than that of the others. Bob looked to Salvatore for help.

"Pasquale," Salvatore explained, "says you are just like all Americans."

"How's that?"

"Because you sleep late."

Bob laughed. "Where did you learn this?"

Pasquale's face contorted. "Huh?" The old man had as hard a time with Bob's textbook Italian as Bob did with Pasquale's dialect. Salvatore translated for him.

"He says this isn't true."

"But it is true," Pasquale insisted.

"And how do you know?" Salvatore asked.

"I just know," Pasquale said.

"Ah!" Salvatore slapped Pasquale on the back of his head, and pushed his beret down onto his nose. Salvatore winked at Bob and held a finger to his temple. "This man is crazy."

"I know," Pasquale repeated. He adjusted his beret and continued to tend to his knives. "I just know."

Salvatore checked the water in the barrel and then picked up the length of rope lying on the table. The three of them set off through a stony field planted with artichokes and olive trees. A spur of the nearby mountains was crowned by a village of white rock and faded rose-tiled roofs. Snow still topped the mountain's highest peak, Petrella. Ever since he was child, the mountain had loomed large in Bob's imagination. His father told stories of his childhood during the war, when his family, driven from their village, lived for a time in one of the hollows below the crest. During the bombing of Monte Cassino, his father climbed to the top of Petrella to watch the Allied bombardment of the monastery. The war had been a carnival for the boy, and the endless night of bombing, a spectacular shower of fireworks, never to be forgotten. To return to Italy and climb Petrella again was an undying wish of his father's. Smoke now curled upwards at the mountain's foot, where farmers were burning weeds and bramble that grew along the edges of their land.

"What a stink!" Pasquale announced when the men reached the sty.

The pig was an enormous gelder, its belly, chest, and haunches caked with mud. It sniffed at their legs through the fence. Bob could feel the animal's warm breath through his jeans.

"Does he have a name?" he asked.

"Name?" asked Salvatore.

"A name," Bob repeated slowly. "Does he have a name?"

Salvatore shrugged. "Pig," he said. "We call this pig."

"You have pigs in America?" Pasquale wanted to know.

"Many pigs," Bob said. "More than in Italy."

The Italians looked at each other with genuine surprise.

"Really?" asked Pasquale.

Bob nodded.

Salvatore entered the pen, his feet sinking into the muck of straw and excrement. Getting on his knees, he slipped a noose around one of the pig's front legs, then passed the free end of the rope to Pasquale. Pasquale and Bob pulled while Salvatore pushed, his knees set heavily into the pig's flanks. The pig grunted deeply and fought them in the mud. Slowly, the men muscled the pig toward the gate. When the pig's head smacked violently against the door jamb, it suddenly squealed, and the noise echoed through the valley. The pig struggled against them harder than before, but the three of them finally shoved the animal out of its pen. The pig grew calm, eagerly nosing the artichokes on either side of the path as Pasquale led it slowly with the rope. Salvatore lightly jabbed at the pig's flanks every now and then with the fallen branch of an olive tree.

"Have you ever done this before?" Salvatore asked.

"No," Bob said, "but I thought you hit it on the head first."

"Before the war, in the time of Mussolini, we did it like that. Then we could not kill our own pigs. We had to take them to a butcher and the meat would be given to everybody. So we did it at night and hit the pig on the head because then it wouldn't make noise when you cut its throat." Salvatore stopped and turned around. He pointed at the mountain with the olive branch. "On the other side of Petrella is Monte Cassino."

"I know," Bob said.

"*Porca miseria!*" Salvatore cursed, and he began to tell Bob of an incident during the war, when the front stretched from Formia on the coast, through the nearby village of Ausonia, to Monte Cassino. Ausonia was used as a German command post by General Kesselring. The people's farms were destroyed by the continual Allied bombing. Bob nodded. Salvatore's description matched what his father had told him. There was hardly a thing to eat, Bob knew. Snow was carried down from Petrella for water.

One day, the Germans garrisoned in Ausonia were sent out to round up all the people in the countryside. They were to be sent to a concentration camp in Rome. Salvatore was a boy at the time, and his family, along with several other families, including Bob's father's, had made shelter together in a stable. This was where the German soldier found them. As they were leaving, the German spotted Bob's father returning to the stable through the field with a Polish deserter. The German took aim and told them to halt. Bob's father immediately dropped behind a pile of rocks. The Pole froze. The soldier threatened to shoot the Pole if he did not find the boy at once. Zia Pina, then a stout matron in her prime, began pleading with the German. She suddenly grabbed his rifle, and another of their group crashed a stone into the soldier's face. The German tried to flee, but he was chased down and stabbed to death.

"It was about this big," said Salvatore, holding up his pinkie.

"What?" Bob asked.

"The knife we had," Salvatore said. "We had to stab him again and again it was so small." Salvatore watched Bob's reaction carefully. "Your father never told you this?"

"My father?" asked Bob with sudden revulsion. He shook his head.

Salvatore smiled nervously. He shrugged, then continued with his story: the next day, a German patrol came looking for the missing soldier. The Italians protested that they knew nothing. The Captain of the patrol warned them that he would begin shooting one of them a minute until the soldier was found. Zia Pina confessed and they unearthed the body. The Captain was so enraged by the mutilation of his man that he immediately executed ten of them. The rest were taken prisoner. But just as they were departing for the concentration camp in Rome, Ausonia was bombed by the Americans, and many escaped into the hills during the confusion of the raid, among them Salvatore, Bob's father, and Zia.

"The streets of Ausonia are made of stone," said Salvatore. "The Germans wore these steel-soled boots so they could never catch us in the street." He laughed, and slapped Pasquale on the back as they led the pig up to the table near the fire in the yard.

"What?" asked Pasquale.

"The war," said Salvatore. "What a time to be young, eh Pasquale?"

Pasquale spit. "*Porca Dio*," he muttered.

The pig's mouth was tied shut, and the heaving bulk was lifted onto the table, its head dangling over one edge. Pasquale tied the hocks, and setting his boot into the pig's rear, pulled its hind legs straight. Salvatore directed Bob to put his weight upon the pig's mid-section and hold taut the rope binding the front legs. The pig's frightened breathing wheezed from its muzzled nose and mouth. Zia Pina appeared with a steaming pot of water, which she poured over the pig's neck while Salvatore cleaned away the dirt. She set the empty pot under the pig's head, and Salvatore scraped the blunt edge of a knife back and forth slowly along the pig's gorge, searching for the vein, before finally digging it forcefully into the pig's throat. He twisted the blade back and forth, and the blood poured across Salvatore's wrist and splattered into the pot. The pig shuddered and twisted, crying mutedly through its clamped jaws, blood spurting with the animal's convulsions. The pig's breathing gradually slackened as the blood drained from its body. Suddenly, the mass lunged. Then it lay still.

Zia Pina took the pot of blood into the house. Pasquale poured steaming water from the barrel over the carcass, while Salvatore scraped his knife across the body. Bristle and skin peeled off as easily as bark from a sycamore. The two men worked quickly, without speaking. When they were finished, the carcass lay white and cold, like a slab of marble. There was the stench of hair and flesh smoldering in the fire.

The corpse was hung upside down from a chain secured to a rafter in the garage. Blood trickled down the jaws onto the pavement, spreading slowly under the soles of Salvatore's laceless shoes as he cut into the loins. The layers of white fat, like heavy folds of warm curd, yielded easily. He continued the incision down the belly, across the chest, and along the throat. He cut open the neck and yanked out the esophagus. Salvatore then opened up the belly, which gave off a humid, fecal odor, and he gathered and pulled the coils of intestine and stomach out of the body cavity onto a wide board that Zia Pina held. The body was propped open wide to dry with staves. Finally, Pasquale draped the hanging corpse in a bed sheet to keep the flies away. The only part that showed was the pig's head. Its small eyes were closed. The mouth gaped. And the skin of the face, with all the stress of the gutted corpse upon it, was creased by thick wrinkles that made the gutted pig appear as if it were smiling.

Bob was still something of a curiosity to his relatives at lunch that afternoon. They watched him closely as he ate. The kitchen was warm and smoky. There was the smell of tripe simmering on the stove, and Bob thought of the dinners at his grandmother's when he was a little boy.

"I haven't had such good sauce since my grandmother died," Bob said to Zia Pina. "If you can cook like this all the time, why don't you come to America with me."

"Ah," she groaned. "I'm on my way to the grave."

"But Zia," Bob said. "Don't worry. We have graves in America, too."

She began to put more pasta into Bob's bowl. He held back her hand. "I've had enough," he said.

She frowned. "But you just said you like it."

"I do."

She gave him another portion and pointed at his dish with her big wooden spoon. "Eat!" she commanded. Pasquale poured Bob another glass of wine. "And drink," he said. "For he who does not drink, does not eat." Bob took another sip of the heavy red wine.

"What do you eat in America?" Zia Pina asked.

"What's America? What's America?" Pasquale interrupted loudly. "Hot dogs! Ketchup! And Coca Cola!" Pasquale laughed and repeated "What's America? What's America?" He then asked Bob, "Do you like it here?"

"Very much," Bob answered.

"Here life is ugly," said Salvatore. He sat drained and limp in his chair. The wine had made him dark and moody. He raised his hand. It was large, black, and dirty, like the burl of a tree root. "Life is ugly here."

"*Madonna!*" Zia Pina exclaimed. She began to pass around clean plates. "Why do you have to talk in such a way"

"Why?" he said. "Because we work and eat and sleep until one day we die."

"Be quiet!" said Zia Pina, and she clanked her serving spoon in Salvatore's plate as she gave him a portion from the pot she had taken from the refrigerator.

There was a silence as she continued to serve the table.

"What are we having now?" Bob asked.

"Try it first," Zia Pina said.

Bob took a bite. The three of them watched him expectantly. "What is it?" he asked.

"Do you like it?"

"What is it?" asked Bob again.

"The pig's blood," she said.

Bob's throat constricted. He looked up, trying hard not to betray his disgust. He avoided Zia Pina's eyes, and gazed past her, out the kitchen window, at the mountains in the near distance. The slopes of Petrella were ruined stairs, abandoned terraces of fig, olive, and orange trees. A marble quarry deeply scarred the mountainside yellow and beige. Bob looked back down at his plate, took another bite, and said through his mouthful, "It's good." He waved for Zia Pina to put more onto his plate.

"Ah!" Salvatore and Pasquale nodded with approval. They clinked their glasses against the wine bottle and swallowed their wine in a gulp.

"Yes," Salvatore said, and he smiled. "He is one of us."

Three Poems

Robert J. Levy

Robert J. Levy is a graduate of St. John's College, Annapolis. These poems are reprinted from his collection of poems entitled *Whistle Maker* (published by the Anhinga Press of Tallahassee, Florida), which received the Anhinga Prize for Poetry for 1986. Last year Mr. Levy was awarded a Creative Writing Fellowship by the National Endowment for the Arts.

In Sickness

Three weeks married to our symptoms
and no change in sight. Hot flashes
baffle us by day. Sudden chills
confuse us through the night. Even
sickness, however, can begin
to look like health in time, and ours,
despite its fever sweats and rheums,
has become domesticated
to a pattern of remissions,
always brief, that allows us both
to spell the other for awhile
before the next attack begins.

Monday you read me Baudelaire
in bed. Tuesday it is my turn
to bring you *meusli* and a peach.
As the days wear on we trade off
the thermometer between us
like an Olympian's baton:
We run our relay race to see
who can take care of whom the best
and for how long. We just can't do
enough for each other. Frankly,
all this fevered giving becomes
quite tiresome after three weeks

sick in bed, and soon we feign all
our infirmities—withered hands,
a vile catarrh . . . anything to
inject a little selfishness
into our lives. What parity
there is in marriage and disease
is slowly weakened to the point
of no return. Still, we are left
much less alone somehow, in love
once more with the mundanity
of being well, having returned,
at long last, to our chronic norm.

The Tristan Chord

More alone with this music than ever before
I find myself thinking of you,
of that other loneliness, and of how
you always had the words for everything,
the way you once called a Beethoven quartet
"the scraping of horses' tails on cats' bowels."

No doubt you could have
talked a rainbow into grayness.
How many times have you walked out from the opera
humming arias like souvenirs?
What you take away with you is candy:
deliciously oblique and self-contained,

a thing that comforts by confining music
to the boundaries of conversation.
But if you would only listen, quietly,
you would hear . . . nothing.
Not music but music's aspiration
to a silence so complete

whatever you might say about it
would be, pathetically, about yourself.
This is the Tristan chord. It melts
like ice in the palm of a word.
Like a shell's susurrus, it sings
of where it came from, where it's going,

but not of what it is. And where do you
fit into all of this? You don't.
You never did. And that's the core of it.
I could tell you how your words have broadened
my experience of art, of life, etc. . . .
They haven't changed a thing. Lately,

I find myself rehearsing the Tristan chord
in all its variations. I've been thinking
how you and I are like two notes
upon a stave, parts of a tune
but not ourselves a tune. I've been thinking how words
escape us—or we from them. I've been thinking

that the search for cadence takes a very long time.

On the Pythagorean Theorem

If we listen to those who wish to recount ancient history, we may find some of them referring this theorem to Pythagoras and saying that he sacrificed a brace of oxen in honor of his discovery. —from Proclus

Just as a bell curve is a kind
of breast with meaning, or graphed
hyperbolae can represent
the coy geometry of lust
(the soft curves of infinite approach
and loss), so too I can believe
that when Pythagoras deduced
the theorem, his sacrifice of
oxen to the gods was not
prompted by piety alone.

Was it for the sake of gods
the dumb beasts were spitted, charred and sent
ethereal, to bovine heaven?
Did he believe the theorem had descended,
courtesy of some mathematical
Prometheus, from on high?

I would like, instead, to think
that the electric "click" of certainty,
flooding his mind like light into a room
where only dark had been before,
was like the voice of a lovely woman
reclaiming him into the world.

At once abstract and visceral,
the "ah ha!" of sudden knowing
was like the "ahhh . . . " of sexual release,
and knowledge struck the belly of his mind
with the neat certainty of wine.

I would like to think he understood
that truth was not otherworldly,
that a fact may reek of burning meat
and its proper offering must be
the smoke from flesh on fire, the smell
of food and sex, the aroma
(corrupt, delicious) of knowledge—
the smoldering thigh pieces of the beast.

The Analytic Art of Viète: A Review Essay

Richard Ferrier

François Viète: *The Analytic Art: Nine Studies in Algebra, Geometry, and Trigonometry from the* Opus restitutae mathematicae analyseos, seu Algebrâ Novâ. Translated by T. Richard Witmer. Kent, Ohio: Kent State University Press, 1983.

As knowledge of the classical languages ceases to be numbered among the tools essential to the educated man, it becomes more desirable to have suitable translations of significant authors who wrote when those languages were the common possession of the learned. While this work has long been done and redone in the so-called humanities, it has always proceeded at a slower pace in mathematics and natural science, so much so that when the new program was established at St. John's College over forty-five years ago, heroic efforts were demanded to produce English texts of such central works as the *Conics* and the *Almagest*. These translations, the hasty offspring of necessity, have remained without competition until very recently, while every year sees new versions of Platonic dialogues or classical tragedies.

Among the mathematical classics included in the new program was François Viète's *Introduction to the Analytical Art*, which J. Winfree Smith first translated for use in the mathematics tutorial. Mr. Smith's version

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is included as an appendix to the translation of Jacob Klein's *Greek Mathematical Thought and the Origin of Algebra.*[1] Mr. Klein argued there that Viète's new algebra, or "specious logistic," as he called it, was the first truly symbolic mathematics and that careful study of Viète's achievement and its development at the hands of Descartes and others would shed light on the symbolic character of modern thought, including the number concept and the notion of scientific law. Those who are skeptical of this interpretation of Viète's work must nonetheless acknowledge that he was a great mathematician. F. Ritter, who wrote the most complete survey of Viète's life and works, accorded him the impressive title, "inventeur de l'algèbre moderne," and the opinion of Augustus De Morgan, writing in the Penny Cyclopedia of 1843, put the same claim in this vivid language:

> If a Persian or a Hindu, instructed in the modern European algebra, were to ask, "who, of all individual men, made the step which most distinctly marks the separation of the science which you now return to us from that which we delivered to you by the hands of Mohammed Ben Musa?" the answer must be—VIETA.

The present volume includes the *Introduction* as well as eight treatises on various mathematical topics. These last, which treat of the theory of equations, multiple and partial angle formulae, solutions to cubic and biquadratic equations, and the application of specious logistic to Geometry, are here published in English for the first time. In performing this labor, Mr. Witmer has facilitated the study of Viète's thought by those who have an interest in his mathematical achievements and philosophical significance but lack the Latin necessary to read the often difficult and dense original text. Such readers may well have been puzzled by Viète's tantalizingly brief discussion of procedure and aims in the *Introduction*, but they have heretofore been unable to interpret that text by comparison with the execution in detail of the program it enunciates. In particular, Viète proposes a threefold analytical art comprising Zetetic, Poristic, and Exegetic or Rhetic, but readers have not been able to agree on what precisely is the nature or function of each part. Poristic has presented the greatest obscurity, but there are doubtful matters in the other two as well. Several of the texts here translated contain the evidence by which these questions can be settled. Exegetic, or the art of actually exhibiting the unknown magnitude in a geometrical problem, is the subject of two of the treatises, *A Canonical Survey of Geometrical Constructions* and *A Supplement to Geometry.* The latter contains Viète's only references to Poristic (pp. 395–97) and gives an example of a complete synthetic solution to the problem of inscribing a regular heptagon in a circle. The meaning of such terms as "specious logistic" and "zetetic" will be clarified by their use throughout all the treatises, but especially the *Preliminary Notes on Symbolic Logistic* (Latin: Ad logisticen speciosam notae priores) and the *Five Books of Zetetica.* Viète's apparent identification of Algebra with the whole of Analysis and his relation to Descartes can be examined more fruitfully through these texts, and the notion of a geometrical algebra, which has been used to describe the second book of Euclid's *Elements,* can be clarified. Particularly interesting in this last connection is the comparison of *Elements II,* Viète's *Survey,* and Paolo Bonansoni's *Geometrical Algebra* translated and published for the first time by R. Schmidt.[2]

And now, with a sense of playing the odious part of Celano at this banquet, I must warn the reader against uncritically falling to. Mr. Witmer's translations are so seriously flawed that the reader cannot trust them in just those places where the greatest interest lies; and, though he may use them, the reader would be well advised to consult Mr. Smith's earlier and superior version of the *Introduction* and, if possible, the Latin original.[3]

Some of these flaws are the fault of the publisher. The numerous solecisms in Greek orthography are annoying but they are no real obstacle to understanding. Others seem to come from a lack of mathematical insight.[4] Readers with knowledge of Euclid will not be misled by hearing the vertex angle of an isosceles triangle called a "vertical angle," though they may be irritated at the irregular usage. The unfamiliar technical term "mesographic" is not synonymous with "cube duplication," as a footnote gives us to understand. It is rather to be rendered as "mean finding" or, as Witmer himself awkwardly puts it, "the discovery of two mean continued proportionals between two given ones [sic]." (p. 395)

The most serious of the deficiencies seem to arise from Witmer's having rejected the possibility that changes in notation imply a qualitative change in the object of mathematics or in the mode in which it is conceived. These are precisely the points that Klein investigated, concluding that Viète was a revolutionary figure in the history of mathematics. Witmer's neglect of these considerations shows up most clearly in his avoidance of all English words that suggest the Latin "species" or the Greek "εἶδος". Viète calls his new algebra "Specious Logistic" because it "is exhibited through the species or forms of things." The last phrase is, in Latin, "species seu rerum formas," an expression that surely is meant to remind the educated reader of Plato and especially Aristotle, who uses exactly equivalent language.[5] Could anyone guess at these echoes in Witmer's rendition (p. 17): "Symbolic logistic employs symbols or signs for things"? In fairness I should point out that here, and in various places through the book, Witmer does give the Latin and, where they exist, various French translations as well as Smith's. But why should the more interesting and accurate rendition be relegated to a footnote? There are numerous indications that when Viète uses "species" and its cognates, he intends to suggest to the reader the philosophic use of these unusually weighty terms. The related word genus is used throughout the *Introduction* in such a way as to force these reflections upon the reader, most emphatically in Viète's statement in Chapter I of the effect of the law of homogeneity, which he calls "the prime and perpetual law of equations." There he employs the significant expression "Solemnis magnitudem ex genere ad genus vi sua proportionaliter adscendentium vel descendentium series seu scala," which Witmer colorlessly renders "a formal series or scale of terms ascending or descending proportionally from class to class in keeping with their nature." Compare with this version Klein's "venerable series or scale of magnitudes ascending or descending from genus to genus . . . " or Smith's "series or ladder, hallowed by custom, of magnitudes ascending or descending by their own nature from genus to genus." I am reminded by this text not only of the hierarchy of species and genus in scholastic philosophy but also of Jacob's dream (Genesis 28, 12), where we find a ladder "scalam" with angels of God "ascendentes et descendentes per eam." Is it on this scale that the heights of heaven are to be ascended? The founders of modernity, as readers of the tradition know, are not unwilling to portray their project as an assault on the heavens through Promethean or even Satanic metaphor. The whole *Introduction*, it will be recalled, cadences with the proud boast "NULLUM NON PROBLEMA SOLVERE": to leave no problem unsolved.

That the transformation of the mathematical meaning of species or εἶδος, particularly in its Diophantine use, is a starting point for Viète's own specious logistic is most plainly supported by Viète's claim that Diophantus used species calculation but hid this fact in order to excite admiration at his wit and ingenuity. This means that Viète understands himself not as innovator but as renovator, which explains the "restitutae" in the title, the comparison to finding "fossil gold" in the dedicatory letter to his patroness, and his plain statement there that his new algebra is "in truth, old." He has cleansed and restored the art of algebra as he had received it from the Arabs by attending to certain clues and traces of a pure original algebra found in the procedure of Diophantus in the *Arithmetica* and the method of analysis as it is discussed by Pappus, Apollonius, Theon, and, in a way, Plato. There are strong reasons, therefore, against translating the conclusion of chapter 5 of the *Introduction* so as to suggest that Diophantus did not have specious logistic and that in consequence he is to be admired, as it were, for operating under a handicap. Witmer's version runs thus:

> [In his *Arithmetic* Diophantus] assuredly exhibits this method in numbers but not in symbols, for which it is nevertheless used. Because of this his ingenuity and quickness of mind are the more to be admired." (p. 27)

Compare this with Smith:

> [Diophantus] presented it as if established by means of numbers and not also by species (which, nevertheless, he used) in order that his subtlety and skill might be the more admired.[6]

In translating the *Survey* and the *Supplement* it is important to keep the language of specious logistic separate from that of classical geometry. Like Toomer's otherwise admirable *Almagest*, Witmer's *Survey* treats the operations of algebra as simply equivalent to construction of figures and composition or decomposition of ratios. To illustrate, the expression "rectangulam sub CF, FG" (Prop. 9, *Survey*) which harkens back to Euclid's "τὸ ὑπὸ τῶν ΒΑ, ΑΓ περιεχόμενον ὀρθογώνιον," should be translated "the rectangle contained by CF and FG." In Viète it signifies a definite individual rectangle. Witmer translates it as $CF \times FG$," turning it into part of an equation, for example "$CF^2+(CF \times FG)= DF^2$." This goes beyond translation and becomes, intentionally or not, an interpretation of the relation between Algebra and Geometry. Both the *Survey* and the *Supplement* concern themselves with just this relation, the bond between geometry and algebra. This is what makes them part of exegetic, the third part of the Analytic art.

> When the equation of the magnitude which is being sought has been set in order, the rhetic or exegetic art ... performs its function ... in regard to lengths, surfaces, and solids, if it is necessary to show the magnitude itself. And in the latter case, the analyst appears as a geometer by actually carrying out the work in imitation of the like analytical solution[7] ... the skillful geometer, though a learned analyst, conceals this fact and presents and explicates his problem as a synthetic one: ...[8]

It is thus no accident that Viète's exegetical treatises employ the language of classical, synthetic, geometry. This could also be shown by a more detailed examination of the diction and structure of the propositions they contain. Viète was here writing in the manner of Euclid. With such texts the pattern for modern English translations ought to be Sir Thomas Heath's translation of Euclid's *Elements*. It is one thing, however, to show that Viète gave these works a geometrical character and content, and another to uncover his reasons for doing so. Perhaps it will not be out of place to attempt an answer to this question by sketching the scheme of the simpler of the two, the *Survey*.

There are three parts to this text. In the first eight propositions, Viète offers constructions as geometrical interpretations of various algebraic operations involving terms of the first and second genera, or degree, as we would say. Proposition 6, for example, is a problem: "Given two straight lines, to find a third proportional." In the 1646 edition, this enunciation is followed by a line set in different type, apparently serving as a kind of title for the proposition following. It reads: "*The Operation of Division.*"

The next five propositions divide into two groups. First Viète proves three theorems on continued proportion. These theorems involve lines forming squares and rectangles suitable for interpreting the three types of quadratic equations that have at least one positive real root.[9] Next come two problems by which the line or lines that interpret the unknown term in the equation are found. In the last seven propositions, Viète accomplishes for certain simple biquadratic equations what these five do for the quadratics.

Everything in the *Survey* is ordered to the problems that construct the line interpreting the unknown. Viète titles such a problem the "mechanice" of its equation, because in it he exhibits the device, the standard and regular procedure, by which the root of such an equation can be exhibited as a line constructed geometrically. Unlike Descartes, Viète does not regard these lines as solutions to the equations. It is in his *Zetetica* (e.g., in *Zetetica* III, prop. 1) that Viète gives the properly algebraic solutions, not, interestingly, as formulae, but rather more in the mode of data stated in words.

Why did Viète give the roots in two distinct ways? In particular, why did he write treatises giving the geometric construction rather than rest in the zetetic, or algebraic, solution? The answer lies in the fact that Specious Logistic, though of the highest universality, remains for Viète an auxiliary procedure. He has yet to make the object of the most universal method the highest object. He thinks a mathematician should proceed in something like this manner: A traditional geometric question is proposed, such as the division of a given line into mean and extreme ratio. This problem is expressed as a quadratic equation in one unknown. After suitable simplifications have been carried out in accordance with the stipulations governing specious logistic, the equation reduces to one of three standard forms. The geometer then consults the *Survey* for the construction that corresponds to an equation of that form. The resulting line solves the geometrical problem. The geometrical problem, I say, not the equation.

The whole figure drawn, including the line sought, *explicates* or *interprets* the equation. A detailed example of this procedure, minus the analysis that yields the equation (Viète is just as cunning as the ancients here), as applied to the inscription in a circle of the regular heptagon, completes the *Supplement*.

Viète is thus more firmly rooted in the ancient tradition than one might think from reading Mr. Klein's account. For him as for Aristotle, quantity exists only as the magnitudes of geometry or the numbers of arithmetic. Geometry calls on algebra in answering its own proper questions and translates the aid into its own proper solutions. The equation as such is not something whose solution is of primary interest.

There is therefore no excuse for the following translation of the first sentence in the *Survey*: "This is a review of the rules of geometric construction by which all equations not exceeding the quadratic can be readily solved."[10] In particular, there is no excuse for translating "explicentur" as "can be solved." There is also no excuse for translating "consectarium ad mechanicen" as "Corollary on the Geometric solution" of an equation. This translation may lead readers into the mathematical details with only occasional misdirection, but with respect to the interesting and problematical features of Viète's work it could well have taken as its motto, NULLUM NON PROBLEMA OBSCURARE.

Notes

1. Translated by Eva Brann (Cambridge: M.I.T. Press, 1968).
2. Annapolis: Golden Hind Press, 1985.
3. All of Viète's extant works are now available in a facsimile reprint of the 1646 edition, with foreword and index by Joseph E. Hofmann (Hildesheim and New York: Georg Olms Verlag, 1970).
4. For example, D should be corrected to 2D on p. 416, and an editor should not keep silent on the related matter of Van Schooten's erroneous emendation of the inference concerning the size of the angles in proposition XVII of the *Supplement* (p. 405).
5. *Physics* 193a31.
6. *GMT*, p. 345. Witmer's error is less excusable in that it also demands bad Latinity; "quibus tamen usus est" simply cannot mean "for which it is nonetheless used."
7. This text misled Klein into thinking that exegetic merely translates into geometry the already resolved equation—something that becomes

possible after the first few pages of Descartes's *Géométrie* but which is never done in the work of Viète. (*GMT*, pp. 167–69, 164)

8. *Introduction*, Chapter VII (*GMT* pp. 346–47).
9. The three types of quadratics are $x^2+px=r^2$, $x^2-px=r^2$, and $px-x^2=r^2$. These are the forms of the quadratic as Viète received the algebraic tradition from the Arabs. Even Descartes holds to this classification in the *Géométrie*, rejecting the form $-px-x^2=r^2$ because its only real roots are negative.
10. The Latin runs "Effectiones Geometricas quibus equationes omnes quae quadratorum metam non excedunt, commode explicentur, ita canonice recenseo." I offer the following: "Those geometrical results by which all equations that do not exceed the bounds set by squares may be conveniently explicated, I list in standard order as follows."

The English *War and Peace:* Paul Scott's *Raj Quartet*

Eva Brann

I. The Post-final Novel
II. The Philistine Satan
III. The Respectful Englishman
IV. The Telling Image

I. The Post-final Novel

I want to begin with a judgment of luminous wrong-headedness. It has appeared twice in the pages of a widely-read weekly book review:

> *The Raj Quartet* is one of the longest, most successfully rendered works of 19th century fiction written in the 20th century.

It is, of course, meant to be put-down, not praise.

What is wrong-headed is the prank played with chronology. Time serves us in no other way than as an imperturbable order of succession. Dates of existence give us the only hard ordering frame we have for the world in its going. Consequently if a novel was completed in 1975, it is a contemporary novel, and should be counted as such. And that is, of course, precisely what is illuminating in the dictum above. It implies that citizenship in one's time does not accrue by mere reason of date of birth but must

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be earned by passing a critical test: The honor of being here and now is bestowed by the craft of critics.

With respect to novels this perverse notion, that the times accredit the work rather than the work the times, takes potently concrete shape. One would think that all the books recognized as novels come to establish a genre: *the fairly lengthy prose fiction.* For such an *ex post facto* genre the exception proves the rule, and so deviations are readily accommodated: There are novels all in rhyme (e.g., Vikram Seth, *Golden Gate*), non-fiction novels that are meticulous reportage (e.g., Truman Capote's *In Cold Blood*), and novels which are one-fifteenth as long as others (cf. Robbe-Grillet's *In the Labyrinth* and *War and Peace*).

In criticism, however, instead of novels there appears something called "The Novel." It behaves not as a genre but as a species: It has a line of evolution within which throw-backs like *The Raj Quartet* are discernible. Since it has become maladaptive, it is probably heading toward extinction, to join the dinosaurs. It is on this evolutionary hypothesis that what David Lodge calls the sermons on the text *"Is the novel dying"* (38) have become a preoccupation of criticism.

There is some agreement about the change in environment to which The Novel is failing to adapt. It is Reality that is killing The Novel (5), or rather the transmutation of reality, not from one state of affairs to another, but out of itself altogether: "Reality is no longer realistic," as Norman Mailer says in *The Man Who Studied Yoga*. What this paradox is intended to mean is that there is no common phenomenal world anymore; our environment has gone surreal. Hence it requires a new novel, one that experiments with "fabulating" techniques: inversions of fact and fiction, randomness, surrealisms both vulgar and sophisticated, and bottomless subjectivism.

Now there has got to be something wrong with this vision of things. That the phenomenal world has illusionistic aspects is simply the wisdom of the ancients, and it is not what is meant here. That our contemporary world has been largely transmogrified into second nature, so that primary beings are harder to find, and that the traditional centers are giving way to fragmented perspectives—these and all the other much-debated features of modernity may make the genealogy of "Reality" harder to trace. But surely the notion that reality is over is a decision and not a finding, a sort of deliberate self-spooking. To put it another way: the coroners of Reality are also its assassins.

Oddly enough, among the motives for writing *finis* to the traditional novel one powerful purpose is precisely the establishment of a purer, sharper reality. Recall that "reality" is Latin for "thinginess." Robbe-Grillet's *"chosisme"* is intended to disinfect things and purify them of their human meaning, so as to restore their pristine independence.

Either way, what is clear is that the putatively dying novel is the so-called "realistic novel." What would be a good description of this, essentially the traditional novel? To begin with, *realism,* the usual critical term, is not quite accurate, for the great traditional novels are full of psychic and surreal episodes. There is, however, a delineation by Iris Murdoch of a novel of *tolerance* which comes closer to the novel that is said to have come to its end:

> A great novelist is essentially tolerant, that is, displays a real apprehension of persons other than the author as having a right to existence and to have a separate mode of being which is important and interesting to themselves.

I must say that the defense of the characters inhabiting great novels in terms of their civil rights gives me a little pause. (Murdoch is defining the great novel as an expression of Classical Liberalism.) Moreover, tolerance seems a faint term for the affirmative sympathy great authors bestow on their characters. Nonetheless, "real persons more or less naturalistically presented" as being "mutually independent centers of significance" are indeed to be found in the works of the novelists she mentions, among whom are Jane Austen and Tolstoy. Now here is a huge claim: Paul Scott belongs in this company.

Let me begin to defend this claim with respect first to tolerance and then to Tolstoy. I shall use as a small preliminary example Scott's treatment of a character who really requires a lot of toleration: Captain Jimmy Clark, one of the old boys of Chillingborough, the public school that plays a fatal role in the book. Scott himself describes him in a later essay as a "wretched cad of a chap," who, regrettably, succeeds in seducing Sarah, the major woman of the novel. Yet for all his sexual cockiness and brutal candor, it is he, and not the gentlemanly chaps, who has the ear for fine classical sitar playing. That too is in Scott's account. It figures in, though it does not outweigh Clark's coarseness toward Sarah. Tolerance does not preclude fine moral reckoning (see III).

As for Tolstoy, the comparison was suggested in passing by David Rubin, whose brief account of the novel is laden with insights. He was corrected in a review by Lawrence Graver, who proposes that Trollope rather than Tolstoy is the proper counterpart. Now I am a loyal Trollope lover, but this comparison seems to me absurd. Trollope is said to have had more than an amateurish knowledge of English parliamentary politics, and he certainly has a wide and nuanced knowledge of English types. But who was ever shaken by the fateful pathos of his setting or his people, as one might be by Scott's? On the contrary, Trollope's world is the quintessence of snugness. That is why he was so fervently revived during the Second World War.

No, the comparison with Tolstoy is much more telling. First, *War and Peace* and *The Raj Quartet* are both long-breathed and large-scened, though they do differ from each other—as the Russia of 1812 differs from the Anglo-India of 1942. Tolstoy's Russians offer indomitable though inertial resistance to the Western invader of their large land; the British depicted by Scott subjugate an immense continent with half-hearted sedulousness. That apotheosis of warm-hearted Russian girlhood, Natasha, finds her entirely lovable completion in bossy, dowdy houswifehood. The ungainly, inhibited English girl Sarah, on the other hand, finds at the end release from family and a dawning love of her own. In both novels these consummations take place in the short epilogue of peace—deadly in the Indian case—that succeeds the great war. The Russian book is elemental and golden, overlaid with the sheen of a serene love of the land; the English book is complex and melancholy, ridden with moral scruple, decline, and loss of faith in England. Accordingly Tolstoy and Scott, who both reflect on history, have opposite views of it. Tolstoy thinks that it is only the integral of very small human differentials, which consequently make all the difference. Scott, sensitive to India's immensity, emphasizes the frailty of human action in the face of history's "moral drift" (1987, 13). Nonetheless, they and their novels end alike, with the children: Just as, in the last pages of *War and Peace*, André Bolkonsky's son Nikolai fervently promises to make his dead father proud, so *The Jewel in the Crown* ends with an episode that postdates the quartet as a whole. Parvati, the lovely young daughter of a dead English mother and a self-exiled Indian father, goes off to her music lesson. She will grow up to be a gifted keeper of the great tradition, the Indian music that her mother had just begun to understand.

Putting *The Raj Quartet* in Tolstoyan company implies of course that it is a great novel. Let me specify the elements that seem to me to make it so:

(1) First there is indeed that widely affirmative mode Murdoch calls tolerance. Elizabeth Bowen says somewhere that "a novelist must be imperturbable." Scott, on the other hand, advises the novelist: "You must commit yourself" (1987, 79). It appears to be the fusion of these, serene engagement and *subtle wholeheartedness*, that is the psychic mode of great novels.

(2) The great novels are full of *resolved complexity*. The net they knit is enormous, but there are no dropped stiches or loose ends. The prime example in the *Quartet* is the underground life of one of the two precipitating characters, Parvati's occulted father, Hari Kumar, the Angli-

cized Indian with whom Daphne Manners falls in love and who is accused of her rape. He vanishes from view after the first book, re-emerges in a harrowing interrogation in the second, only to disappear, as it seems, for good. His absence hovers over the second half of the novel: Has the author forgotten him, left him dangling? But he returns toward the end, though not *in propria persona*—those connections are missed. He reappears rather as a printed voice, a voice of infinite melancholy, writing essays about the lost Eden of England, indeed about Chillingborough, essays which are signed with the name Philoctetes, the betrayed archer-hero with the incurable wound.

(3) A great novelist has in mind thousands of bits of knowledge which when selected appear to accrue significance on their own. Scott refers to this property as "*graces bestowed*" (1987, 215). He lists as examples both the name Daphne, which is a laurel native to *Eurasia* and the name of a nymph metamorphosed into that shrub while running from a god; and the name Philoctetes, which Scott relates to the Great Archer Hari. But such felicities are legion in the novel.

(4) In all the great novels I know there is an inextricable *reciprocity of scenes and characters*, of atmosphere and action. *The Raj Quartet* is full of subtle deeds and fine-spun conversations which slowly weave a magnificent panoramic tapestry. But it also exudes strong, strange-familiar redolences, enveloping auras, which seem to precipitate the individual figures. In Section IV below something will be said about how Scott achieves this effect.

(5) The occurrences and deeds of great novels are explicit. In particular is the evil done *literal evil*. I shall dwell on this matter in the next section.

In sum, a very great novel, a post-final novel, was completed little more than a decade ago, although The Novel was supposed to be dead. Or as Scott puts it, inveighing against the "literary body-snatchers . . . the sort of people who prove that the novel is dead because they want it to be": "*Well, if the novel is dead, all I can say is that it's having a lovely funeral*" (1987, 193).

II. The Philistine Satan

The Raj Quartet has something *War and Peace* lacks: an evil presence of enormous pathos. It is the almost vibrant desolation around this person which confirms Scott as a "tolerant" novelist in the most positive sense.

This villain is Ronald Merrick, whose name, as so many in this novel, sounds overtones, here those of merit gone wrong. There are, to be sure, other unadmirable characters in the book. Authorial tolerance, as has been said, does not preclude personal or moral aversion. There is, above all, Sarah's mother Mildred Layton, a languidly snobbish, rigid Memsahib, who displays, however, her own sort of arid valor. There is also Pandit Baba, the fanatical behind-the-scenes instigator of rebellion, Merrick's ultimate nemesis, who has, for all his slipperiness, a certain blunt righteousness. But neither of these has the odor of unholiness that hangs about the monstrously efficient District Superintendent of Police in Mayapore, later a captain in the Indian army, who acquires a defacing scar and a prosthetic hand.

But great treatments of human evil do not take refuge in indeterminate demonisms. They have the courage of their moral revulsion: Definite crimes are committed. Take for example that dark evil which preoccupies Marlowe in Conrad's *Heart of Darkness*, surely the greatest novelette of our century. For all its ineffable horror, there are also namable misdeeds: Kurtz has allowed himself to be worshipped as a god, with human sacrifices. Or consider how much more vaporous Dostoevsky's *Possessed* became when the first editor prudishly excluded Stavrogin's confession, which reveals the actual deed corresponding to his spiritual perversion: He had seduced and driven to suicide a little girl.

Scott's Merrick tortures and molests prisoners, and drives one of them to suicide. He manipulates superiors, blackmails subordinates, and abuses confidential knowledge—always working discreetly, though at the limits. Moreover, the explanation of this appalling man's conduct is given along straightforwardly secular lines, in terms of an unfortunate conjunction of sexual pathology, social inferiority, and tearingly ambiguous racial feeling. This not unsympathetic account, rendered after Merrick's lurid semi-suicidal death, comes from the most understanding quarter, the wise and decent sophisticate and long-inactive homosexual, Count Bronowski (Book IV, 594).

It is because there are real crimes and secular diagnosis that Merrick can acquire theological gravity. This perspective is provided by one of the most moving figures in fiction, Barbie Batchelor, the missionary spinster whose book, *The Towers of Silence*, is the intense heart of the *Raj* series. She is the sort of person one could not stand to spend an hour with in a social setting. She scurries about officiously and talks compulsively. But Scott follows her fate from her own center, from the threatening void behind her chatter, through the spells of "imaginary silences," moments of insight when she does not know whether she has actually uttered anything, to her final mute madness. Her despair derives from love deprived of an aim; above all she is oppressed by an intense devotion to an absconded god.

This woman's precarious sanity is finally unhinged as a direct result of her encounter with Merrick. She is packed and ready to leave Pankot when she first catches a glimpse of him; she gasps "both at the sight of a man and at the noxious emanation that lay like an almost visible miasma around the plants along the balustrade which had grown dense and begun to trail tendrils." In the course of their meeting—he had sought her out as he had gone after other victims he had chosen: men, women, finally a child—he teaches her about despair. In particular he reveals to her the despair behind the suttee-like death of her friend and heroine, Edwina Crane. Miss Crane had set herself afire after the fatal beating of the schoolmaster Chaudhuri, who had been protecting her from a mob on the road from Dibrapur:

> "There is no God. Not even on the road from Dibrapur."
> An invisible lightning struck the veranda. The purity of its colourless fire etched shadows on his face. The cross glowed on her breast and then seemed to burn out (375).

Having thus undone Damascus, he sends her off on a tonga which, overburdened with the weight of her trunk (it contains the testimonials of her life), careens down-hill to calamity. Her last sane words are: "I have seen the devil."

That Merrrick is Satanic is utterly clear: He has a sort of non-being; he is "a man," as Guy Perrin, the fresh hero of the last book says, "who comes too late and invents himself to make up for it"—too late, that is, for the kind of domination he longs to exercise. He hunts and catches souls. He purveys despair. But he is a smaller and newer devil than Milton's "lost Archangel" who rules Pandemonium in self-confident grandeur. Merrick is goaded to middle-class *ressentiment* by the frosty superiority of the Chillingburians, white and black, not possessed by rebellious pride. What is more devastating, he is a renegade without a Lord, consigned to traveling to and fro in India and to riding up and down in it with no one to report to. He is a devil in a world without a god, a humanistic devil, a human devil, a human being.

Now I am mindful of the cheap frisson to be gained from that notorious interpretational identity: "The ostensibly human character X is really the mythical Y," the Great Earth Mother, say, or the Wicked Witch of the West. But aside from the fact that Scott's indicators are unmistakable, it is actually only to Barbie Batchelor that Ronald Merrick is the devil, and his essentially human deviltry is the direct complement of God's absence: In a world from which God has absconded a man can be a demon.

The wonder is that this frigid philistine can invest his own perverted person with such a bleakly piteous aura. Scott's early novels, some of which are clear preludes to *The Raj Quartet*, are all about the moral struggle of lonely men against forces of disintegration. It is almost as if Merrick had been molded out of the negative to their common essence.

III. The Respectful Englishman

As the complement to the delineation of the policeman's private perversion, the novel as a whole bears a moral mission. It is an engrossing fact that the mission is a noble failure, at least in one of its two facets. When faced on a certain occasion with a direct question by an Indian about the present-day contribution of his work, Scott had no positive answer (1987, 147). Nonetheless he made it clear, and others understood, that he was combatting two evils: the ignorance of the English not so much about India—that is beyond novelistic cure—but about their own moral responsibility for its fate (1987, 157); and the ingrained lack of respect the English aliens have for the dark-skinned Indians in whose land they are camping. It is for racial arrogance alone that Scott shows real contempt.

Now *The Raj Quartet* is indeed a deeply absorbing history lesson in the rise and fall of the raj, the English rule of India. So far the mission is fulfilled.

It is otherwise with the respect of the British for the Indians. For this has in turn two aspects, a racial and a religious one. The germinal and controlling event of the book is the consummation of Daphne's and Hari's love in the Bibighar Gardens, and her subsequent rape by a gang of hooligans, for which Hari is arrested by Merrick. True to his promise to Daphne (exacted by her for his protection, not hers) he never divulges the truth of the affair. Hari Kumar is for Daphne Manners a full human being; in the intimacy of this affair color is nothing. But he is also Harry Coomer, a Chillingburian, Englishman through and through—indeed the novel's English gentleman *par excellence.*

If color is at least in one decisive instance conquered, Indianness, Hindu Indianness, is another matter. Except for Kumar and the above-mentioned Chaudhuri, "B.A., B.S.C.," who "did not profess to be a Christian" but "on the other hand, . . . did not profess any other religion," no hero of the book is born Hindu. Indeed there are many unsavory Hindus like the Pandit. In *Staying On*, which bears to the *Raj* tetralogy the relation that a satyr play has to an ancient tragic trilogy, it gets worse. There we find that mountainous monument of petty corruption, who exceeds the nastiest Britisher in nastiness, Mrs. Boolabhoy.

In truth, the Indians, who, like the two Kasims, have the authorial respect are Muslims, and even when apostate they are not unmindful of their history. Young Kasim is not the only Muslim in this novel who dies an unassuming hero's death defending English women. I do not know whether Scott was aware of the fact that he favors the Muslims. The inclination certainly goes way back in India novels.

"One does not write out of one's feelings for books but out of one's feelings about life," says Scott (1987, 160). But books are part of a writer's life, the more vitally so the less he is playing "Can you top this" with the tradition. The book vital to the shaping of *The Raj Quartet's* mission was of course E. M. Forster's *A Passage to India*. Scott was puzzled and disturbed by Forster's final judgment that the liberal Fielding and Dr. Asiz cannot be friends. Forster's earth and sky say: "No, not yet," "No, not there." But now it should be possible, Scott thinks, to portray such a friendship (1987, 1962). Perhaps so, but it is to my point that Asiz is in fact a Muslim. There is an old, old history of British revulsion from Hinduism (Rubin, 8, 168), and Scott does not break out of it. Perhaps in Hinduism the West may face its uttermost antithesis, where appreciative respect is perilous. I do not know. But I do know that Scott's failure should give us pause in our incessant sanguine calls for understanding our non-Western fellow humans by means of heaps of self-denigration and a few three-credit courses. It can't be done: At most we can examine ourselves to discern what is inalienably ours, what is insuperably alien, and what is residually common.

Accordingly, this English novel is more than anything about being British, that is to say, about being an English man or woman cut off from and forgotten by England, camping on alien soil, coping with obligations and succumbing to spiritual temptations not known at home. Such highly local trials bring out deeply human quandaries. Except for the color question, Scott's sympathy is inexhaustible, so much so that he has been, absurdly, accused of being an "imperialist-manqué." But then the novel has also been called anti-British: If it is, then anxious reproaches are not a part of love. In fact, of course, the charges balance out, confirming the work as the "moral dialogue between writer and reader" that Scott thinks a novel should, among other things, be (1987, 149). He does not think, however, that the moral effect is the essential function of a novel.

Here is what a novel, more centrally, is: It is "a view into a private vision of reality." (1987,104). For Scott this definition has a meaning at once deep and precise.

IV. The Telling Image

The deeper meaning is that a novelist works with being and with a perspective on being, with reality acknowledged and with reality viewed. It should be said here that the catchword "reality" includes all sorts of observed otherness, from infinite landscapes to intimate reveries, from hardest thinghood to surrealist visions: Viewed reality is precisely reality viewed as experience, "*human* reality" (107). The implication of this complex notion is that one might work out—not here, though—a metaphysics specific to the "the novel of tolerance," the traditional great novel *par excellence.* Of course a novelist of Scott's stature was deeply preoccupied by what one might call "applied metaphysics." His reflections, scattered but cohesive, are to be found in the essays collected in *On Writing and the Novel.*

The more precise, almost technical meaning of Scott's definition is that a novel is the telling of an image. Here is the author's most specific idea of "*what a novel is*":

> A series of *images*, conveyed from me to you, in such a manner that my view of life is also conveyed—BUT ONLY TO ONE PERSON AT A TIME: THE READER (consenting adults). *IT IS THAT READER I'M WRITING TO* (212).

So to begin with, and as he continually emphasizes, a novel is a communication; indeed it is a sort of love affair between the writer and each separate reader. This intention distinguishes him from the experimental writer, whose responsibility is to keep the genre alive by his innovations and the critics at work by his sophistication.

That is not to say that Scott is not a very clever narrator. He uses a great multiplicity of means: audacious perturbations of time, such as reprises, anticipations, parallelisms; large varieties of sources, fictive and real, such as diaries, newspaper accounts, descriptions of cartoons; and, above all, the several kinds of narration: direct, oblique, third-, second-, first-person narrative. In fact there are in *The Raj Quartet* two distinct narrators. The first of these is an anonymous inquirer who investigates the ramifications of the Bibighar affair in the first book. The second is Guy Perrin, the character obviously closest to the author. He is introduced in the last book as a "breath of fresh air," to represent a healthier "modernity," a man who baffles Merrick's designs on him (214). We learn in *Staying On* that the delicate understanding between him and Sarah, first expressed in the aftermath of the Hindu massacre of Muslims during which they had failed to save their friend Ahmed Kasim from self-sacrifice, had resulted in a happy marriage. The "question of who is telling the story"

(212) was on Scott's mind; one might say that its asking—whose first occurrence is in Plato's *Republic* (393)—is one chief mark of a self-conscious, reflective writer.

The telling, the narrative, is packed into the "small, hard rectangular object" (114) which the reader gets to hold. The material book and the telling between its covers are successive reductions of a first, originating element: the *image*. Here then is Scott's most concise definition of a novel:

> A novel is a sequence of images. In sequence these images tell a story (74).

Hence the language of a novel is for all its verbal linearity not a telling but a showing (74). This secret of Scott's novels is first set out in an essay, antedating *The Raj Quartet*, called "Imagination and the Novel" (1961). And indeed, the earlier novels which, though fine in themselves, look in hindsight like exercises for the *Raj*, are full of such images. In *The Chinese Love Pavilion*, for example, a crucial image is the "landscape without figures," "the intimate distances preserved behind glass," pictures of India painted by the narrator's grandfather. They are shown to signify the complication introduced into the romantic love of the land by the presence of real people, dark-skinned natives and white dispensers of justice. Here one can see how the image invokes the moral preoccupation of a novel. Indeed, in "Method: The Mystery and the Mechanics" (1967), Scott goes so far as to say that writing which does not grow out of an image but in which, conversely, the image is fitted to the text, is flat and tenuous (75). He "won't begin until the images start coming" (212). The mystery—for Scott that image is the writer's mystery—must precede the mechanics.

Again, in *The Birds of Paradise* the narrator is beset with images, often flashing forth as from a lost paradise (Swindon). However, mention of this novel gives an opportunity to make a different, though essential point: Scott's aboriginal image is not a literary image in the usual sense. The dead *paradisea regia* of the title and the very live parrot with which the narrator makes do are—very resonant—literary images: of beauty fallen prey to consumption, of rajahs and of the Raj. But the image Scott means is another thing: It is a vision, a literal vision of the visual and, secondarily, of the auditory imagination, a sight before the mind's eye with the specific properties of internal vision:

> First, . . . the primary materials, from both the author's and the reader's point of view, are the images. Secondly, . . . because they are images—illusions of a mobile, audible, human activity—there are perhaps no actual *rules* to follow which will ensure they hold together, or to depart from which will

lead to collapse. *You could say that because the images are not tactile, the question of their holding together simply doesn't arise ...* (110).

This passage presents the canonical properties of visual imagery established in the disciplines and sciences that study them: freedom from the laws of motion and of inertial bodies; elsewhere Scott adds yet another, release from temporal determinacy (83). But it also says something about the special relation that the image-based novel establishes between author and reader: The reader's absorption of the novel recapitulates its genesis in the writer's imagination: Both begin with the image.

And end with it. Scott's theory is entirely abstracted from his practice, and accordingly the *Raj* books begin with, are sustained by, and end on an image, the specific spontaneous vision from which and into which the novel grows. One might say that the novelistic image acts somewhat like an Aristotelian form: It guides the novel's coming into being and it is the shape of its completion.

The governing image of *The Raj Quartet* is that of a girl running (82, 84). The writer starts "bombarding the image with experience," the image here being a girl he's met briefly in Calcutta, a husky, awkward girl (85) as both Daphne and Sarah will be. The image opens up, shows the plot, the problems it contains. *The Jewel in the Crown* begins with this running girl, gawky Daphne Manners fleeing from the Bibighar catastrophe. It closes with a running girl, Parvati, her graceful golden-brown daughter running to her music lesson. And the whole quartet ends with a double image in a song by the Muslim poet Gaffur: the bowman choosing his arrows and the girl running with the deer—Hari and Daphne raised to a mythical vision.

The running girl is indeed the human figure of the image, but behind that figure is a scene, an Indian setting, vast and variable, "conveying to a girl running ... an idea of immensity." Hence the *whole* image consists of the landscape *and* the figure in it: a reciprocating vision of intimating atmosphere and poignant action.

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