

Experimental Identities: Quantum Physics in Popular Science Writing and Virginia Woolf’s *The Waves*

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Virginia Woolf’s *The Waves* (1931) is a novel about the impossibility of defining identity. Throughout the novel, the six main characters utter soliloquies in which they employ image after image to define their own beings and experiences, the very profusion of the images indicating the impossibility of the task. Each image is succeeded by another, and none is final. At the end of the novel, one of the characters, Bernard, engages in an attempt to “sum up” (191) his life, but finds that he cannot do it, for the simple reason that his life is inseparable from those of the people around him:

And now I ask, “Who am I?” I have been talking of Bernard, Neville, Jinny, Susan, Rhoda and Louis. Am I all of them? Am I one and distinct? I do not know. . . . I cannot find any obstacle separating us. There is no division between me and them. As I talked I felt “I am you”. This difference we make so much of, this identity we so feverishly cherish, was overcome. (231)

Identity, this passage makes clear, is indefinable, uncategorizable, because it is at once multiple and boundless. Bernard is at the same time a multiplicity of people – “Bernard, Neville, Jinny, Susan, Rhoda and Louis” – and, as he says elsewhere, an “unsubstantial territory” (10); the “division”, or demarcation, between himself and those around him does not exist.

As Woolf scholars have long recognized, *The Waves* is deeply immersed in contemporary science. The waves of the title are not simply the waves of the sea; as intangible entities, permeating the bodies of the characters, constantly subject to the play of light, they insistently recall the waves of electromagnetic radiation which, according to early-twentieth-century physics, were ubiquitous in the physical world. When the popular science writer James Jeans stated that “the tendency of modern physics is to resolve the whole material universe into waves, and nothing but waves” (77-8), he could as easily have been referring to the “universe” of *The Waves*. The scientific resonances of *The Waves* were also recognized by contemporary commentators; Woolf’s friend Goldsworthy Lowes Dickinson wrote to her that the novel “makes clearer to me what literature really is. It’s not (as it is so often in fact) a kind of antithesis to science. It’s science made alive.” (Forster 233). It is the contention of this article that one of the ways in which *The Waves* makes science “alive” is in its application of the entities and processes of contemporary science to questions of human identity. More specifically, it sets out to show that Woolf employs the language and structure of quantum physical experiments in order to reiterate Bernard’s perception that the self, far from being fixed or definable, is multiple and unlimited. However, this is not to accept the binary distinction between science and literature that Dickinson’s letter seems implicitly to endorse (he implies that without Woolf’s literary intervention, science would be dead). On the contrary, I will demonstrate that Woolf’s project of using concepts drawn from physics to destabilize fixed models of identity is one that she shares with contemporary popular science writers.

Moreover, I offer a new way of considering the relationship between Woolf and contemporary popular science (and literature and science more broadly). Instead of

constructing a straightforward narrative of influence between the two disciplines, this article demonstrates that Woolf and the science writers are involved in a reciprocal process of influence, which can be modelled by the feedback loop. Literary and scientific writers, it suggests, draw upon one another's ideas because they resonate with their own pre-existing concerns. The result of this process of feedback is that the two domains in question – quantum physics and human identity – become more and more associated in the cultural imagination. Through a focus on Woolf, a writer detached from scientific institutions but engaging with the popular manifestations of scientific discourse, we can thus arrive at an improved understanding of the way in which science transformed, and was transformed by, the culture of the 1920s and 30s.

The physicist and popular science writer G. P. Thomson is a good example of a scientific commentator who draws upon conceptions of identity employed in contemporary modernist literature. Thomson's book *The Atom* (1930), which sought to explicate contemporary scientific understanding of the structure of the atom for a popular audience, employs the language of identity in order to describe the ontological status of an electron in the light of recent discoveries in quantum physics. Discussing the theory that all matter is actually made up of waves, he says "one might suppose that the electrons had lost their identity and merged into a general diffuse mass." He goes on to say that such a view is inaccurate; in fact Pauli's exclusion principle, which states that only one electron can occupy a particular quantum state at one time, "is in its very essence a statement of the stubborn individuality of electrons and of the impossibility of merging them together" (*The Atom* 208-9). The various theories of quantum physics are thus articulated and compared in terms of the implications that they have for the identity of the electrons in question. The dichotomy, moreover, is the same one that Bernard discusses in *The Waves*: between "stubborn individuality," the need to define one's identity, and the tendency of that identity to dissolve, or "merge," into the "mass." By using the language of identity to describe subatomic particles, Thomson is inviting his readership to apply the discoveries of quantum physics to their own sense of self. This process of extrapolation from science to human identity was a fairly common one in the popular science writing of the 1920s and 1930s; the biologist J.B.S. Haldane, for example, wrote that contemporary understanding of cellular biology meant that we should view ourselves as "communities" of cells rather than as single individuals, and that if we all commonly used the pronoun "we" to refer to ourselves, "we should understand a good deal more about how we work" (57). Where scientific writers employ the language of identity to explicate scientific concepts, in *The Waves* Woolf engages in a reciprocal process of using the language of science to describe identity. Woolf and the science writers thus both use metaphor to map the two domains onto one another. Thomson's book, *The Atom* (1930), was in Woolf's library, and she could very likely have read it before completing *The Waves*. Reading the two books alongside one another thus provides a useful exemplar of the feedback between literature and popular science in the 1930s.

The age of quantum physics began in 1900 with Max Planck's discovery of quanta, and with the interpretations of his discovery published by Planck, and, in 1905, by Albert Einstein. Einstein used Planck's discovery that energy could only be absorbed or emitted by an atom in discrete bundles to propose the concept of the wave-particle duality of electromagnetic radiation. Planck's discovery was also used by Niels Bohr to modify Rutherford's 1911 solar system model of the atom. In a paper of 1913 Bohr showed that, because atoms could only absorb energy in multiples of Planck's constant, there were a limited number of orbits (or energy levels) that an electron in the atom could occupy. When an atom absorbed or emitted energy, one of its electrons moved

from one energy level to another. Bohr's model was found to produce a small amount of mathematical error. In 1924, Louis de Broglie showed that the error could be eliminated if the electrons in the atom were treated as waves with a discrete set of frequencies, thus extending the concept of wave-particle duality to matter. In a paper of 1926, Erwin Schrödinger proposed that these waves should be thought of as waves of probability; the intensity of the wave at any particular point corresponded to the probability that the electron was located at that point. The waves did not have a real existence as such but were mathematical entities, propagated in an imaginary sub-aether.

Over the past twenty years, Woolf critics have become increasingly attentive to the importance of physics to Woolf's fiction. There have been various analyses of the effect that quantum physics has on Woolf's representation of the nature of perception, mainly focusing either on Heisenberg's Uncertainty Principle (Tolliver Brown 41-2) or on the concept of quantum entanglement (Ryan 175). Other critics, most notably Gillian Beer, have commented upon the ubiquity of waves in Woolf's writing; Beer argues that the insubstantiality of matter in *The Waves* is a response both to popular accounts of quantum physics and to earlier developments in atomic physics (*Wave, Atom, Dinosaur*). Michael Whitworth's important study of the relationship between physics and modernism, *Einstein's Wake*, takes as its central tenet the idea that scientific concepts are imported into literature in the form of metaphor, and particularly influence the formal qualities of texts. He argues, for example, that the metaphor employed by popular science writers to explain Schrödinger's theory, that of a stormy area which consolidates itself into a particle, can be traced in *The Waves* both in the image of a "fin in a waste of waters" and, formally, in the groups which form and then dissolve throughout the novel (164). Rachel Crossland, meanwhile, demonstrates the importance of dualities in Woolf's writing. Crossland argues that Woolf's use of duality was not entirely determined by contemporary physics (in fact, many of Woolf's articulations of duality were written prior to wave-particle duality becoming a fully worked-out theory). Instead, she demonstrates, Woolf was working out her own version of duality and of complementarity at the same time as the physicists were developing theirs.

Most notably for the purposes of this article, various critics have drawn a connection between quantum physical concepts and Woolf's depiction of identity. Whitworth, for example, connects Woolf's writing to a long historical tradition of viewing atoms and electrons as metaphors for the self (147). Both Michele Pridmore-Brown and Sue Sun Yom, meanwhile, argue that Woolf represents a dialectical identity that is associated with wave-particle duality; Pridmore-Brown, in her political analysis of *Between the Acts*, argues that Woolf promotes a combination of democratic community and a critical and hence anti-totalizing individualism, positions which correspond respectively to a "wavelike" and "particlelike" existence (418), while Sun Yom argues that Woolf represents a "cycle of rhythmically imaged condensation and expansion" which is "in itself a stylistic manifestation of wave and point." (148). Many of these analyses however (with the notable exceptions of Beer, Whitworth and Crossland) fail to consider the specific route through which quantum physical concepts find their way into Woolf's writing. As a result, as Whitworth points out, they are often anachronistic (Whitworth 20); the concept of quantum entanglement, in particular, was developed in 1935, too late to be incorporated into all but two of Woolf's novels, *The Years* (1937) and *Between the Acts* (1941). Moreover, the lack of attention paid to the specificities of influence means that critics often find themselves pointing out vague resemblances between physical concepts and narrative features, without identifying specific linguistic or formal links.

However, by following Whitworth and Beer in focusing on Woolf's reading of popular science writing, it is possible to avoid a reliance upon vague resemblances or anachronistic connections. Popular science functions as a crucial missing link between, on the one hand, quantum physical concepts, and, on the other, Woolf's multiple, diffuse identities. The concepts of quantum physics are not transmitted to Woolf directly; she receives them via a medium that already associates physics and identity. Moreover, by attending to the specifics of Woolf's use of language and imagery we can see her responding to particular quantum physical experiments and experimental processes. The connection between Woolf and quantum physics therefore becomes no longer a matter of resemblance, but of specific conceptual transmission.

In the 1920s and 1930s, a plethora of popular science books were published to help the non-specialist to comprehend the new and difficult concepts of quantum physics; among these, some of the most successful were *The Mysterious Universe* (1930) by James Jeans and *The Nature of the Physical World* (1928) by Arthur Eddington. The BBC, as part of a general attempt to make its broadcasts educational, produced many talks by physicists, which often included detailed expositions of scientific theories. These talks were published in the BBC journal, *The Listener*, along with reviews of scientific books and regular scientific columns by A. S. Russell. A regular listener to the wireless or reader of *The Listener* would thus have been kept fairly *au fait* with the latest developments in quantum physics; a review of *The Nature of the Physical World* by E.A. Milne, published in April 1929, for example, explained Heisenberg's Uncertainty Principle. Important scientific experiments were also reported, including one of the experiments that will be the focus of this article: G. P. Thomson's electron-diffraction experiment, which helped to confirm the wave-particle duality of matter. In August 1929 Thomson himself gave a broadcast describing his experiment and its consequences. Given that Woolf was an avid listener to the wireless, it is likely that she would have heard some of these programmes. Newspapers such as *The Times* reported on meetings of important scientific bodies such as the Royal Institution and the British Association, often summarizing or quoting from the papers given; these reports will be important to this article.

Critics who have explored Woolf's relationship with quantum physics have tended to seek to establish a definite line of influence, dwelling particularly upon the popular science books that she might have read, or on her reading of periodicals with scientific content. Whitworth examines the various periodicals associated with Woolf's social network, particularly *The Nation and Athenaeum*, of which Leonard Woolf was the literary editor. *The Nation and Athenaeum* regularly published reviews of popular science books which summarized (albeit usually briefly) the books' scientific content. Woolf very likely read Jeans' *The Mysterious Universe*; in her diary, she reports reading a book by him, and earlier that month reports that she discussed the book with friends (Bell 337; 340). Woolf's friendship with Bertrand Russell also makes it highly likely that she would have read, or at least have been familiar with the ideas within his book *The ABC of Atoms* (1925), which discusses some of the early discoveries of quantum physics. As Anna Snaith points out, the picture of a "dot . . . surrounded with strokes" that Eleanor draws in *The Years* recalls Russell's description in *The ABC of Atoms* of the structure of a helium atom as "a somewhat primitive wheel, with four spokes" (Snaith 466). Similarly, although there is no definitive evidence that Woolf read Eddington's *The Nature of the Physical World*, several critics have pointed out the striking similarities between Eddington's description of the difficulty for a scientist to walk through a door when he is aware that the floor he is standing on "has no solidity of substance" (328) and the difficulty that Rhoda in *The Waves* has in taking a step

when she feels as though she will fall through the surface of the world (Whitworth 160). Less often discussed by critics is G.P. Thomson's *The Atom* (1930), a book that was in Woolf's library, and which she may very likely have read. Focusing on the popular science books, broadcasts and newspaper articles that Woolf may have read or heard allows us to retain a degree of specificity in our analysis of the transmission of scientific concepts. Rather than assuming the existence of a homogenized scientific discourse, we can thus, in Sally Shuttleworth's terms, take "into account the social and economic conditions underlying the diverse formulations and specific appropriations" of scientific ideas (*Charlotte Brontë and Victorian Psychology* 5).

Woolf's familiarity with the concepts of quantum physics is fairly conclusively demonstrated by a casual reference in a letter she wrote to Hugh Walpole in July 1930. Walpole had recently returned from a lecture tour in Germany.

I envy you, on the strength of your flying picture of German life: Einstein etc. But I always hope other people's lives aren't so wildly exciting as they seem. Another touch, and I should jump from my orbit in a vain endeavour to be you. I've been only Mrs Woolf of 52 T.S. all the summer, seeing Ethel Smyth, Vita, Christabel, Lytton and so on. I wish I could think of anything to make you envious. I like printing in my basement best, almost: no, I like drinking champagne and getting wildly excited. I like driving off to Rodmell on a hot Friday evening and having cold ham, and sitting on my terrace and smoking a cigar with an owl or two. (Nicolson 188-9)

The mention of "orbits" would, in itself, be inconclusive; it would be as likely (if not more likely) to refer to the orbit of a planet than to electron orbits. However, planets do not "jump" from their orbits. As we have seen, one of the foundational discoveries in quantum physics was Niels Bohr's discovery that there were a limited set of orbits within an atom that an electron could occupy; this distinguished their orbits from those of planets, which could have a radius of any length. When the atom absorbed or emitted radiation the electron would "jump" from one orbit to another. Bohr's model was based upon the theory developed by Planck and Einstein that light, as well as acting as a continuous wave, sometimes acted as a discontinuous stream of particles. A sense of discontinuity is essential to this passage. Although Woolf, like an electron, can jump from her orbit, this would be a "vain endeavour," because she cannot as a result become Hugh Walpole; he is in one of the orbits that she cannot occupy. She is anxious, however, to show him that she herself is not merely "Mrs Woolf of 52 T[avistock] S[square]," but can occupy many orbits of her own; she is a publisher, a social being, a companion of owls. This passage is highly relevant, not merely because it proves Woolf's familiarity with the foundational ideas of quantum physics, but also because it shows her aptness to use those ideas to think about identity. Here, the discrete set of orbits an electron can occupy is made to correspond to a question that Woolf finds deeply important: the limited number of things that a person can be.

This tendency to apply quantum physics to questions of human identity finds its fullest expression in *The Waves*, in which Woolf employs the language and forms of quantum physical experiments to depict the shifting nature of her characters' identities. The first experimental process to be considered is the use of a beam of radiation to determine the position of an electron; the electron would scatter the radiation, and the pattern of the scattering could be used to pinpoint the electron's location. The process was crucial to Schrödinger's wave theory, which posited that the identity of an electron was fundamentally altered by the act of observation. Schrödinger's wave theory was a

specific version of wave-particle duality that offered a probabilistic interpretation of the waves associated with a particle. Prior to being observed, the position of the electron is modelled by a probability distribution. The waves associated with the electron correspond to this probability distribution; their intensity at any given point corresponds to the probability of that point being the location of the electron. Once it has been observed, however, the position of the electron is limited to a single point. Implicit in Schrödinger's theory is thus the idea that observation removes indeterminacy; prior to being observed, the electron has no fixed location.

In a passage at the beginning of *The Waves*, one of the characters, Louis, describes his own identity in a way that has striking resonances with Schrödinger's theory. The passage occurs during a pivotal scene in which Louis is standing on his own by a hedge, experiencing an epiphanic moment in which he becomes unified with the natural world. His sense of unity is destroyed, however, when another character, Jinny, looks through a hole in the hedge and sees him:

[L]et me be unseen. I am green as a yew tree in the shade of the hedge. My hair is made of leaves. I am rooted to the middle of the earth. My body is a stalk. I press the stalk. A drop oozes from the hole at the mouth and slowly, thickly, grows larger and larger. Now something pink passes the eyehole. Now an eye-beam is slid through the chink. Its beam strikes me. I am a boy in a grey flannel suit. She has found me. (8)

As with Schrödinger's electron, observation fundamentally alters the nature of Louis's identity. Before it is observed, the electron can be considered to occupy an infinite number of points at once; in the same way, before he is observed by Jinny, Louis's identity is pluralistic and indeterminate. He is a boy standing next to a hedge, but at the same time he becomes the hedge; he turns "green," his hair becomes "made of leaves," and he becomes "rooted" to the earth. He is both the subject and the object of his own actions; he is described as pressing a stalk, but at the same time he says that his body "is a stalk." Consequently, his identity proliferates and all subjectivity is removed; in the phrase "A drop oozes from the hole at the mouth," "the mouth," while inviting an association with Louis's mouth, is objectified and disowned through the use of the definite article. His identity is thus disseminated into the world around him. However, all this indeterminacy and unity with the external world is instantly removed when Louis is seen by Jinny. Like the electron, which takes on a specific position once observed, observation reduces Louis to a singular identity; he becomes "a boy in a grey flannel suit." While being "unseen" allows for a proliferation of identity, to be seen is to be limited.

As well as thus mimicking the shift from indeterminacy to determinacy in Schrödinger's theory, Woolf's use of language recalls the specific scientific process whereby that shift occurs. As Woolf undoubtedly knew, people see objects when light reflected from the object enters their eye; when Jinny sees Louis, however, Louis says, of Jinny's eye, "Its beam strikes me." The beam moves from the observer to the observed, mirroring the experimental process in which a beam of electromagnetic radiation was fired at an electron. Louis's identity is thus made to be singular and fixed in precisely the same way in which, in Schrödinger's model, a probability wave is reduced to a single position. The description of Louis as "a boy in a grey flannel suit" is significant because it implies that Louis has been reduced to a set of social markers. The limiting effect of observation is thus equated with the limiting effects of a set of social definitions that do not allow room for the multiplicities and ambiguities of the

private self. Social convention allows no space for Louis to interact with others as half boy, half tree; in becoming a social being, therefore, he must give up the extended, multiple version of himself.

The effect of observation upon identity is a persistent preoccupation in *The Waves*. Later in the novel, Bernard describes being observed by another person in a social setting in the following terms:

I, who had been thinking myself so vast, a temple, a church, a whole universe, unconfined and capable of being everywhere on the verge of things and here too, am now nothing but what you see – an elderly man, rather heavy, grey above the ears (234).

Bernard's selfhood initially stretches to the limit, to "the verge of things"; like a wave, it extends everywhere. Bernard's self-description in this passage seems to set up a wave-particle duality that has significant resonances with Schrödinger's theory, in which a particle, although potentially localizable (Bernard is "here too"), can be at any point on a wave (he is "capable of being everywhere"). The listing of incompatible possible identities – "a church, a whole universe," "on the verge of things and here too" – insistently recalls the probability wave, which models mutually contradictory possibilities. Bernard's multiplicitous, indeterminate identity is reduced by observation, however, to the body as it is perceived by others; he becomes "an elderly man." After his companion has left, Bernard rejoices that

Now no one sees me and I change no more. Heaven be praised for solitude that has removed the pressure of the eye, the solicitation of the body, and all need of lies and phrases. (236)

Observation is a "pressure," reducing the self to a single, social manifestation, and its removal liberates the self and allows it to be once again aware of the potential identities of which it is "capable."

Schrödinger's wave theory has considerable formal correspondences with Woolf's depiction of identity in *The Waves*. It suggests that by determining the position of a particle all its previous indeterminacies are foreclosed, just as, in *The Waves*, the necessity of interacting in a social setting immediately collapses the ambiguous, diffuse self into a single entity. Moreover, the role of observation in delimiting the position of an electron in Schrödinger's theory corresponds to the social pressure that reduces the self in Woolf's depiction of identity. This is not, however, to suggest that Schrödinger's theory entirely determines Woolf's representation of identity in *The Waves*. It is rather that Schrödinger provides her with a language in which to express her pre-existing perception that social definitions of identity are too limiting, underestimating and repressing the multiple, ambiguous aspects of the self. More specifically, she draws upon the language of actual quantum physical experiments in order to dramatize the incompatibility of actual and social selves.

In a corresponding but obverse process, scientific writers and commentators employed the language of identity in order to emphasize the significance of quantum physical theories. For example, *The Times* reported a lecture at the Royal Institution in which the lecturer stated that within Schrödinger's theory "the individuality of the electron seems to vanish and to disappear in a continuous system of stationary waves" ("M. Painlevé in London" 16). This formulation is important because it assesses Schrödinger's theory in terms of the effect that it has on the "individuality" of

subatomic particles. Electrons are being attributed identities, and it seems to matter when those identities are compromised. The modernist (and, specifically, Woolfian) sense of a dispersing identity is transposed onto the quantum universe. Woolf and the scientists are thus involved in a complementary process, each contributing to the increasing association between quantum physical concepts and human identity.

Another experiment that finds resonances in the language of *The Waves* is G.P. Thomson's electron-diffraction experiment. The experiment was crucial in confirming Louis de Broglie's theory that matter exhibited wave-qualities. It consisted of firing electrons through a thin film of gold. The gaps between the gold atoms diffracted the electrons, causing them to produce an interference pattern similar to that produced by diffracting X-rays (Navarro 154). The interference pattern was captured on a photographic plate, and consisted of a series of concentric circles alternating between light and dark. The experiment was regarded as a crucial piece of evidence supporting the theory that matter, like light, had wave properties. It was reported in *The Times* ("The Electron and Beyond" 11), and G. P. Thomson gave a broadcast on the radio describing the experiment and its implications; his broadcast was transcribed in *The Listener*, complete with an illustration (Thomson, "New Discoveries about Electrons"). The experiment was also described by Jeans in *The Mysterious Universe*, also complete with illustration (42-3, Plate II).

When the characters in *The Waves* meet for a dinner party, Susan describes the transformative effects when Jinny enters the room:

She seems to centre everything; round her tables, lines of doors, windows, ceilings, ray themselves, like rays round the star in the middle of a smashed window-pane. She brings things to a point, to order. Now she sees us, and moves, and all the rays ripple and flow and waver over us, bringing in new tides of sensation. We change. Louis puts his hand to his tie. . . . And I, though I pile my mind with damp grass, with wet fields, with the sound of rain on the roof and the gusts of wind that batter at the house in winter and so protect my soul against her, feel her derision steal round me, feel her laughter curl its tongues of fire round me and light up unsparingly my shabby dress, my square-tipped finger-nails, which I at once hide under the tablecloth. (95)

The description of "rays" centred around "a point" are highly reminiscent of the pattern of concentric circles produced by Thomson's experiment. These rays, moreover, form part of a description in which Jinny seems to be ascribed both particle and wavelike qualities. She "brings things to a point," but at the same time her rays "ripple and flow and waver over us." Her effect on her surroundings is at once ordering, corresponding to the definitive certainty of a "point" (or a particle), and diffuse, a transformative spreading outward of influence. Just as Thomson's experiment confirmed that electrons acted as both waves and particles, so Jinny's interference pattern demonstrates her dualistic nature. Two conceptions of selfhood seem to coexist in Jinny's dual identity; on the one hand, the self reduces the diverse aspects of its experience into a single, indivisible identity, whilst on the other hand the self becomes indistinguishable from its surroundings, spreading ever outward in ripples of influence. The duality is mirrored by the grammatical structure of the passage; the repeated technique of listing nouns which precede the main verb of the sentence gives the impression of repeatedly circling around the main point of the sentence. Moreover, Jinny's complex, manifold identity is indicated by the synaesthetic existence of her "laughter"; Susan can "feel" it, and it is able to "light up" other people. The combination of the tactile and the visual suggests

the commonality in the natures of matter and light proven by Thomson's experiment. Jinny is not only both a wave and a particle, but in being so she becomes both light and matter. Her identity thus becomes self-contradictory and all-encompassing.

While Woolf thus uses the language and structure of Thomson's experiment to represent Jinny's identity, Thomson himself, in his expositions of his experiment, engaged in the obverse activity of using the language of identity to describe subatomic entities. An article in *The Times* in September 1928, reporting on a meeting of the British Association in which Thomson described his experiment, referred to Thomson's "belief that electrons were distinct individuals and not merely theoretical units of a communistic action." Thomson is described as "saying in an amusing phrase that they had as much individuality as mathematicians themselves." ('British Association' 17). Thomson clearly took the opposite view to Woolf, emphasizing "individuality" rather than the multiplicity of identity. However, it is notable that he seemed to think that the individuality of electrons needed to be defended. Where Woolf uses wave-particle duality to question the fixity of human identity, Thomson uses the (apparently secure) individuality of the mathematicians to defend the fixed identities of the electrons. Such reciprocal comparisons make it clear that both literary and scientific writing were forging a link between subatomic and human identities, so that, ultimately, the fixity of one became dependent upon the fixity of the other. Moreover, despite (or perhaps because of) Thomson's defence of individuality, it is evident that the duality and indeterminacy of subatomic particles were seen as posing a serious threat to traditional notions of human identity.

However, it is not enough simply to determine that Woolf and contemporary science writers are involved in a collective project of mapping together quantum physical entities and human identity. How does such a project come about? How can we theorize the relationship between Woolf's work and the work of popular science writers such as Thomson? How are concepts such as indeterminacy and the instability of identity passed between disciplines? Studies of Woolf and physics often implicitly adopt a contextual approach, offering contemporary physics as an explanation for various aspects of Woolf's texts. Paul Tolliver Brown, for instance, implies that relativity and quantum physics can be used to explain "the permeable boundaries of consciousness" in Woolf's novels. He assumes a one-way influence between science and literature, describing how *To the Lighthouse* "melds" and "reflects" physical theories (40). One-way models of influence are challenged, however, by recent theoretical work on literature and science, which has tended to stress that the two disciplines are involved in a complex network of influence. Approaches which view science as a context for literature have been found to be reductive because they accord a primacy to science, and seem implicitly to be based on an assumption that science deals with truth, thus ignoring its status as a cultural discourse, inflected by contemporary concerns, assumptions, and modes of perception. As Paul Peppis argues, science should be viewed

not as a stable and authoritative discipline, objective and universal, but as a shifting and varied constellation of writers, theories, and texts precisely and complexly "located in its social and cultural context," as L. J. Jordanova explains (4).

Equally, the contextual approach relegates literature to a derivative, almost parasitic status, depicting it as drawing ideas from contemporary science without offering anything in return. At the same time, literary writers are portrayed as offering creative,

critical responses to science, thus transcending their historical moment in a way in which scientists, constrained by the knowledge of their time, cannot do; such readings thus fall into the trap of "granting literary texts more historical agency than they grant scientific documents" (Peppis 8). Critics have increasingly moved away from the unidirectional model of influence, towards a perception of literature and science as equally culturally-constructed, mutually influential disciplines, and have begun to attend to the specificities of the influence that literature has upon science. Sally Shuttleworth, for example, explores the use of Victorian novels as "case studies" within psychological texts (*The Mind of the Child* 10). As Gillian Beer explains,

this is not a one-way process with science as the origin and others as its intellectual beneficiaries only. Scientists work with the metaphors and the thought-sets historically active in their communities. (*Open Fields* 8).

Literary writers, in helping to determine those "metaphors" and "thought-sets," inform both the selection of phenomena deemed worthy of scientific investigation, and the way in which scientific findings are constituted through language.

Following George Levine, who in his edited collection *One Culture* conceptualizes literature and science as sharing a common discourse, theorists of literature and science have increasingly come to view the relationship between the two in terms of metaphors of shared or interacting networks and fields. N. Katherine Hayles, for example, advocates a "field theory" in which all writing is part of a cultural "field" of influences, through which the concerns of both literary and scientific writers are determined by a generalized "climate of opinion." Hayles' theory denies one-way narratives of influence: "In a field model, the interactions are always mutual: the cultural matrix guides individual inquiry at the same time that the inquiry helps to form, or transform, the matrix." (*The Cosmic Web* 22-3). However, Levine and Hayles's models run the risk of underestimating the distinctions between disciplines, and bringing science and literature onto a single, homogenous level. From this point of view, Gillian Beer's more pluralistic model of "open fields" seems more helpful, as it construes literature and science as "fields" which, though ostensibly separate, have boundaries which are "open" and constantly transgressed (*Open Fields*).

Both models, however, have the limitation of being primarily spatial. Desirous to avoid the unidirectional model, these critics depict literature and science as temporally coexistent, occupying a contemporaneous web. Their models are thus of more use to critics who wish to take a snapshot of a particular historical moment, tracing a particular set of concerns across an entire culture, than for studies such as this one which attempts to locate a single writer within her cultural nexus and to examine the ways in which her writing inflects, and is inflected by, contemporary discourse. The field models do have a temporal dimension, positing mutual influences and interactions, but their emphasis is much more upon the interrelations of the disciplines as a whole than upon the ways in which concepts are transmitted from writer to writer, or from text to text. What is lacking in the field of literature and science is a model that takes account both of the existence of mutual, two-way influences *and* of the specificities of conceptual transmission. The model proposed by this article is the feedback loop.

The term "feedback loop" refers to any manifestation of a formal pattern whereby an initial action leads to effects which then reinforce that action. It has been traced within multiple contexts and phenomena, from computing to the philosophy of mind. Its generality makes it an extremely useful theoretical model, and it has been adopted by several critics looking at the relationship between science and culture. In

her book *Chaos Bound*, N. Katherine Hayles uses it to describe the mutual influence of science and technology; she argues that particular scientific concepts become crystallized by their incorporation into technologies, and then once again become the subject of scientific inquiry (xiv). Laura Otis, following Hayles, applies it to the relationship between neurological theories and communication technologies. The circular influence that Hayles and Otis attribute to science and technology can equally be applied to science and literature. Literature and science can be thought of as mutually confirming disciplines, with particular ideas being passed from one to the other in a loop of influence. Within this context, a specific version of the feedback loop is particularly valuable: that is, the audio feedback loop found in sound technologies. Objects such as electric guitars have a resonant frequency, determined by their molecular structure. If a sound wave with a frequency equal to the resonant frequency of the guitar is emitted by the sound system, it will resonate with the guitar, causing its strings to vibrate and thus causing the same sound wave to be emitted once again by the sound system at a higher volume, beginning the cycle again; the resulting sound is a loud screech. This form of feedback is particularly useful because it involves the concept of resonance; the sound waves resonate with the pre-existing natural frequency of the guitar. In the same way, literary writers can be seen to take up scientific ideas, and scientific writers to take up literary ideas, because they resonate with their pre-existing concerns. In this view, the concepts of duality and indeterminacy in quantum physics resonate with Woolf's pre-existing preoccupation with the multiplicity of identity, causing her to use scientific models and scientific experiments in her depictions of selfhood. Conversely, the multiplicity and fluidity of identity found in modernist writing in general, and Woolf's writing in particular, resonate with the preoccupations of the physicists, causing them to emphasize the implications that quantum physics has for identity.

The feedback loop model has two main difficulties; firstly, it posits an original source of sound, which according to the analogy would correspond either to Woolf's multiple identities or to indeterminacy within scientific discourse. To attribute this original role to scientific discourse would be once again to fall into the trap of viewing literature as derivative, while to attribute it to Woolf would be to overestimate her influence on a discourse that extended beyond the English-speaking world. The original source is, however, unimportant; it seems in any case most likely that the concepts of both indeterminacy and the multiplicity of identity emerged from a variety of sources. What is important is the increasing association between the two ideas within literary and scientific discourse. Secondly, the model places Woolf's writing and the writing of contemporary scientists on different levels of reality, one being the sound system that is influenced by and amplifies particular concerns, the other the external context through which the concerns pass before re-entering the system. To identify Woolf's writing with the sound system runs the risk of attributing more agency to literary writing, and equating scientific writing with reality. Ideally, both Woolf's writing and scientific writing should be viewed as occupying the role of the sound system in the analogy; they are both impinged upon by concerns which, resonating with their pre-existing preoccupations, are amplified, and re-enter a cultural matrix.

The model is, however, most useful in its introduction of the concepts of feedback and of resonance. By attending to the feedback between Woolf and contemporary scientists, we can trace a circular chain of causality that removes any need to describe a one-way influence. The critic seeking to trace associations between Woolf and quantum physics is no longer confuted by concepts that seem to appear in Woolf's writing prior to their articulation by contemporary physicists. Michael

Whitworth observes that "a retrospect of Woolf's earlier novels reveals that Woolf had developed many aspects of her own wave/particle model of the self in anticipation of the physicists" (162). According to the feedback model, such an observation no longer forces the critic to conclude that Woolf's use of the terms "wave" and "particle" occurs independently from their usage by contemporary physicists; it merely illustrates the extent to which literature can inflect scientific discourse. The concept of resonance, moreover, is enormously useful because it implies a mutual activity. Terms frequently used in the context of interdisciplinarity, such as "influence" and "reflection", construe the discipline receiving the ideas as entirely passive; when an object resonates, however, there is an interaction between the frequency of the wave impinging on the object, and the resonant frequency of the object itself. Both are necessary terms that produce the eventual result. Neither science nor literature must be relegated to a derivative status; instead they produce independent ideas which then resonate with one another and become associated. The feedback loop thus provides us with a useful model for determining precisely how literature and science are, in Sally Shuttleworth's terms, "mutually constitutive fields" (*The Mind of the Child* 4): it enables us to trace the processes whereby the two disciplines constitute one another.

The workings of the loop of influence between Woolf and scientific writers become apparent when the question of scientific language is considered. In *Open Fields*, Beer argues that scientific writers tend to attempt to circumscribe the terms they use through the "stable locking of single signification" (181); by restricting their words to a single meaning, they hope on the one hand to avoid misunderstanding and on the other to exclude readers outside their institutional group who cannot understand their particular terminology. Writers in scientific journals such as *Nature*, Beer argues, use "a concentrated technical address to like-minded and similarly prepared readers, emphasizing specification of meaning and offering few means of entry to non-specialists" (*Open Fields* 160). However, as soon as the text is read by readers from other fields, alternative significations arise. Beer gives as an example Darwin's application of the word "races" to cabbages; his usage attempts to limit the word to its botanical applications, but when drawn upon by other writers its anthropological resonances are activated (156). When science finds its way into literature, in particular, the way in which literary language thrives upon ambiguity of meaning means that the significations of scientific terms inevitably proliferate (164).

However, the opposition that Beer sets up between, on the one hand, scientific limitation of meaning, and, on the other, literary proliferation, is complicated by the surge in popular science writing in the 1920s and 1930s. Popular science writers, far from attempting to exclude readers from outside their institutions, hope to give their works as broad an appeal as possible. They rely upon the idea that, for example, events in the interior of an atom are of interest to people who are not atomic physicists. It is, therefore, entirely in their interests to gesture towards alternative significations of their terms, particularly towards significations that seem to have relevance for the non-scientific reader. The use of the word "individuality" when applied to an electron, for example, suggests, without drawing an explicit analogy, that the ontological existence of the electron might have implications for the identity of a human being. However, in choosing which meanings to encourage, the scientific writers are inevitably informed by a pre-existing idea of which concerns are culturally important enough to provoke interest. It is in this way that Woolf's influence on scientific writers largely functions. Her works feed into a larger cultural interest in the multiplicity of identity which the scientific writers respond to, deliberately making their meanings ambiguous in order to suggest that contemporary physics supports a view of identity as multiple.

An example of scientific discourse that fosters an association between physical entities and human identities is an article in *The Times* by the physicist and popular science writer Arthur Eddington, in which he discusses the impossibility of tracing the exact path of an electron when two come into contact (a consequence of Heisenberg's Uncertainty Principle). Eddington describes the impossibility of knowing, after two electrons have approached closely together, which one is which, using the analogy of two golf balls:

Let us trace the adventures of two electrons (*alias* golf balls) before and after a close approach during which the above-mentioned breakdown of ordinary conceptions will admittedly occur. After the incident our two golf balls are lying on the fairway. Which is yours, and which is mine? ("The Electron 'Dummy'" 13).

Lying behind this description are two major assumptions: that it matters whether or not the identity of an electron remains consistently traceable, and that the identity of electrons is in some way associated with the identity of human beings. Eddington later refers to the "ambiguity of identity" that is consequently introduced into the scientist's study of the electrons in question (13). The analogy sets up a causal association between the identities of electrons and human beings. If the identity of the golf ball-electron becomes indeterminate, it follows that there is some confusion between the identities of the two people involved; the boundary between what is "yours" and what is "mine" has been removed. Both of these assumptions (that electrons have identities, and that their identities are comparable to human identities), and the consequent idea that any shift in understanding about the nature of electrons throws doubt upon the stability of identity in general, could not exist without a preceding sense that identity is shifting and permeable, a sense that writers such as Woolf helped to foster. Moreover, Eddington's decision to use the golf ball analogy is very likely influenced by a desire to appeal to his audience by over-emphasizing the implications that the discoveries of quantum physics had for everyday reality. Thanks to the focus of modernist writers such as Woolf on the self-conscious, self-reflexive life of the individual consciousness, identity had come to seem essential to the form that reality took. Woolf can thus be seen as being instrumental in determining Eddington's associations between physics and selfhood, even if he never came into direct contact with her work. Neither literature nor science has the primary role; both are implicated in the increasing association between scientific entities and human identity.

If we accept that there exists a feedback loop between literature and science which, in the 1920s and 1930s, results in an intensified sense that human identity is multiple and indeterminate, what does this actually tell us about the literature in question? How does Woolf's use of the language and structure of quantum physical experiments actually affect her depiction of identity? Is it not merely the substitution of one set of terms for another, the language of science standing in for the language of identity? Here, Gillian Beer's concept of transformation is extremely useful. In *Open Fields*, Beer examines:

the transformations undergone when ideas enter other genres or different reading groups, the destabilizing of knowledge once it escapes from the initial group of co-workers, its tendency to mean more and other than could have been foreseen. (115)

As has already been made clear, by incorporating scientific language into her novel Woolf makes that language "mean more and other" by participating in a wider cultural tendency of associating scientific concepts with human identity. However, it should also be noted that here, again, the effect is mutual: scientific language cannot be incorporated into (and transformed by) literary discourse without in some way transforming that discourse. In this case, the use of scientific language transforms Woolf's novel by introducing into it the scientific form of the experiment. Not only is *The Waves* experimental in the literary sense; it also employs the experiment as a formal principle. The novel is essentially an observation of how entities behave and change under a particular set of conditions. The entities in question, the identities of the six main characters, are constantly shifting: Jinny develops "rays" on entering a room full of people; Louis is multiple and indeterminate when concealed behind a hedge, but a singular "boy" when viewed by another person. Throughout the novel, the images associated with each character are constantly in flux, taking on new significations, blending with the images of the others. Their identities are fundamentally experimental.

Critical accounts of *The Waves* often construe its version of identity as being the result of a struggle between two opposing alternatives, usually with a political or psychological inflection. Michael Tratner, for example, argues that Woolf is "torn between preserving her individuality – gaining a room of her own – and trying to speak for the masses" (96), while Barbara Ann Schapiro describes Woolf as being involved in a "struggle *not* to succumb to a . . . dedifferentiated state" (187). Such readings arise from, and contribute to, an insidious tendency to view Woolf as a fundamentally irrational writer, a tendency founded upon gender stereotyping and upon a biographical interpretation of her writing that depicts it as a therapeutic practice rather than a conscious intellectual endeavour. Once we become aware of Woolf's use of scientific experiments in her depiction of identity, however, it becomes clear that the apparently conflicting versions of identity in the novel are actually part of a consciously inscribed flux: that, as well as representing identity as multiple and expansive, Woolf depicts it as constantly changing, resisting any attempt at definition or circumscription. By making the flux of identity the central focus of the characters' self-conscious monologues, moreover, Woolf makes it clear that the observation of one's own shifting identity is a pleasure and an artistic endeavour in and of itself. At the same time, she contributes to a broader cultural paradigm in which identity is tested and redefined through the processes and language of physics.

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