ARTICLE

THE WRITING OF SCIENTIFIC NON-FICTION

Contexts, Choices, Constraints

In the sociology of science recent studies of scientific texts and writing practices consistently indicate two themes: (1) scientific writing arises within and is responsive to specific social situations, and (2) the author controls (or constructs) what appears in the scientific text and thus can use the text to advance the author's interests.[1] These studies, together examining a wide disciplinary and historical range of texts, convincingly refute the traditional view that scientific texts simply and unproblematically report on nature as revealed through empirical investigation.

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But recognizing that scientists indeed write their papers and that they write within a set of historical-social exigencies seems to make problematic science's claim to make valid, successful, or successively better formulations about nature, unless validity, success, and goodness are defined purely in terms of social and personal interest. In short, indexicality and interest seem to cut the ground of reference to nature out from underneath scientific non-fiction. If scientific non-fiction, moreover, finds itself with little to distinguish itself from fiction, then all other forms of non-fiction would seem to lose whatever claim they have to the representation of reality.

From a relativist perspective, such problematization of non-fiction is not troublesome; it is indeed the point. But for any more agnostic investigation, the question of the status of non-fiction cannot be set aside, if for no other reason than scientists themselves operate on the assumption that they are formulating statements of at least provisional validity about nature. In order to understand scientists' practices on their own terms and to evaluate the substance of their operative existential belief, we need to take seriously the claim that scientists write a kind of non-fiction. Furthermore, if scientific papers do succeed in encapsulating some knowledge of nature beyond the social operations of participation in the scientific community, we must spell out the mechanisms by which this is accomplished.

This paper investigates how scientific texts are made accountable to nature even though a text arises within a scientific community, employs communal language and concepts, pursues the concerns of that community, and furthers the individual's interests within that community. The investigation here, however, turns to the process by which a text is created to find out how meanings are created and embodied in the text. This study goes beyond a reconstruction of the implied relations embodied in the text to examine the material relations between the emerging text and the author/scientist, the relevant community, the prior knowledge, and observed nature. These relations will be examined by the positioning of the emerging text against the contexts and interests within which it arises and by notes, draft, and revisions that reveal the text's coming into being.

The case to be studied is the emergence of a paper "Measurements of β-Rays Associated with Scattered X-Rays" by Arthur H. Compton and Alfred W. Simon, originally appearing in *Physical Review*, 25 (March 1925), pages 306-313 (see appendix). This case material was chosen because of the completeness and availability of the relevant notes, draft, and revisions in Compton's notebooks. I worked from the photocopy of Compton's notebooks at The Center for the History of Physics at the American Institute of Physics in New York; the originals are deposited in St. Louis at the library of George Washington University. Such draft materials for writing in physics are rare in the public archives. Unlike writers of fiction and poetry, who recognize that a text emerges only gradually and who therefore save the record of the literary workshop for posterity, physicists seem to save very little of their intermediate paper.

Although both Compton and Simon are credited as joint authors of the "Measurements" article, all notes, draft, and revisions appear in Compton's third notebook in Compton's handwriting. The assumption that Compton was the actual writer and the shaping intelligence is further supported by the fact that Simon was still a graduate student when the article was written; moreover, the paper fits closely to the theme and issues of Compton's research program while Simon never pursued similar work except in collaboration with Compton.[2] Finally in the draft of the article, Compton unthinkingly starts to refer to himself as the author. Thus it appears safe to assume that Simon's role was to assist in the laboratory, and all the shaping and formulating was Compton's.[3]

The materials from Compton's notebook consist of about a dozen pages of notes on works by other authors, twenty-two pages of calculations and design sketches for a polyphase transformer, fourteen pages of analysis of photographic data, and seventeen pages of draft and revisions. Material related to other work Compton was engaged in is interspersed, such as a draft of exam questions from a course Compton was teaching.

Context and Response

The article in question is one of a series of follow-up articles to Compton's major discovery paper, "A Quantum Theory of the Scattering of X-Rays by Light Elements," in which he announced what is now called the Compton Effect.[4] In retrospect the Compton Effect is considered the first empirical verification of the quantum theory, but verification of quantum theory was not Compton's purpose in pursuing his experimental program or publishing his findings.[5] He was instead concerned with explaining x-ray scattering effects which he had been investigating in classical electrodynamic terms.[6] He found that the only way to account for the wavelength shift of x-rays occurring during scattering was to assume that the incident radiation imparted a quantum of energy to the target electron, which then recoiled in a definite direction; in order to conserve momentum and energy a new quantum of scattered radiation (of longer wavelength and thus less energy than the incident radiation) had to be emitted in an appropriate direction.

Almost immediately upon publication, Compton's discovery underwent a series of challenges, which Compton answered by carrying out further experiments and publishing the results, disconfirming the challenges and refining the theory.[7] It was in this context of challenge and response, of elaboration and bolstering, that Compton pursued the work that would lead to the "Measurements" paper. The more evidence of the most varied kind he could find, the more likely he would be to gain acceptance of his original discovery claims.

At about the same time as Compton had published "A Quantum Theory of the Scattering of X-Rays by Light Elements" in May 1923, C.T.R. Wilson (and slightly later W. Bothe) identified in cloud chamber experiments on X-ray scattering secondary β-ray tracks substantially shorter than photo-electron tracks.[8] Compton immediately saw that these shorter tracks could represent the recoil electrons he hypothesized in the quantum theory article. He wrote a letter dated August 4, 1923, to that effect to *Nature*, which published the letter in the issue of September 22, 1923.[9] Although at that time Compton continued to be mostly concerned with data revealing wave-length shifts, which data he kept gathering during the following year, he clearly understood how the cloud chamber findings filled out his work. He assimilated the cloud chamber findings into his consequent papers, often in lengthy discussions indicating how they supported his theory.[10]

Wilson's and Bothe's data, however, only offered a rough correspondence to Compton's theory, as Compton later noted: "They have shown that the direction of these rays is right, and that their range is of the proper order of magnitude."[11] The roughness Compton ascribes to the use of insufficiently hard and too heterogeneous x-rays. The "Measurements" article can thus be seen as Compton's attempt to tie down the connection

between his theory and the cloud chamber tracks more firmly and precisely by redoing other people's experiments in a way more appropriate to his programmatic purposes. He would then obtain support for his theory from a kind of data not at all available when the theory was first framed; such data, confirming the predictive power of the theory, is rather persuasive.

In this way we can see the "Measurements" paper motivated and shaped in specific ways by Compton's theoretical program, discoveries by other scientists as reported in the literature, the desire for closer measurement of the phenomenon, and Compton's persuasive intentions. Contextual factors provide pressures and offer opportunities to gather fuller, more precise, and more focused data about the observed radiation — confirming and adding detail to the representation of nature embodied in Compton's theory. His social interest in establishing the proposed phenomenon leads Compton to search actively for passive constraints of new and more precise kinds; criticisms in the literature actively push him again to seek passive constraints that make his formulation more likely; finally, new techniques, actively created (although embodying passive constraints in what they can accomplish and in the results they produce), provide opportunities for closer looks at the purported phenomenon, adding new passive constraints to the formulation.

Specifically, this set of forces and opportunities led Compton to design experiments and write a paper reporting those experiments,

1. adopting Wilson's cloud expansion apparatus
2. referring to and discussing his own quantum theory of scattering
3. employing higher energy (shorter wave-length) incident radiation than Wilson and Bothe
4. designing and employing a method of obtaining more homogeneous incident radiation than Wilson and Bothe (consequently reporting data for higher energy, more homogeneous data)
5. developing theoretical predictions about aspects of the recoil electrons measurable through the Wilson apparatus
6. and discussing the correspondence between the theoretical predictions and the experimental data.

These effects of the rhetorical situation correspond to the major structural features of the resulting paper. Compton, indeed, alludes to these effects when he describes the paper at the end of the opening paragraph:

> The present paper describes stereoscopic photographs of these new rays which we have recently made by Wilson's cloud expansion method. In taking the pictures, sufficiently hard x-rays were used to make possible a more quantitative study of the properties of these rays.[12]

Within the stylized terms of the field, the paper describes constraints imposed by the results of more precise measurements. By showing that Compton's theory is in conformity with ever-increasing passive constraints, the article seeks to establish fact-like status for Compton's claims.[13]

Another aspect of the rhetorical context consisted of one particular challenge to Compton's quantum theory of scattering. Bohr, Kramers, and Slater claimed that at the particle level the laws of conservation applied only statistically.[14] Compton's theory required event by event application of the conservation laws; up to that point, however, Compton had established the recoil phenomenon only on an aggregate basis through measurement of radiation wavelengths. Wilson's cloud photographs provided a way of capturing and measuring single incidents and were, therefore, the ideal means of refuting Bohr, Kramers, and Slater. The full and explicit refutation of the statistical argument was to be made by Compton and Simon in a subsequent article — "Directed Quanta of Scattered X-rays"[15] which appeared in *Physical Review* six months after the "Measurements" article — but the desire to refute the challenge remains an implicit shaping force on the earlier article. The effect can be seen in the emphasis given in both the abstract and the full paper on conclusions and evidence that the scattering occurs on an event by event basis, with each event maintaining conservation of momentum and energy. This emphasis is in fact increased in revision. Again, attack on the formulation provides pressure to seek and reveal passive constraints, consonant with the original formulation.

Laboratory Decisions, Events, and Results

The effects of the rhetorical situation are first realized in Compton's laboratory decisions before their full implications in the text are realized. The laboratory decisions, such as the use of the Wilson cloud apparatus, designing a more precise control over the incident radiation, the design of the scattering experiment, the choice of which plates to use as data, and the particular measurements taken from those plates, all have an effect on

the final article, both in terms of the procedures described and the data reported. The first three decisions are design decisions based on the characteristics of the phenomenon investigated and the properties of the equipment, as both have been revealed through previous investigations. The Wilson apparatus, for example, is used only because it has earlier revealed tracks that Compton can identify with recoil electrons. Compton goes to great lengths to make design decisions that will permit observation with the desired precision; twenty-two pages of his notebooks are devoted to designs for a polyphase transformer that will provide him with stable enough voltage to provide homogeneous incident radiation of calculable energies.[16] The experimenter can choose from among available technologies, but those technologies suffer many passive constraints. The experimenter cannot use impossible machines, nor can he make machines do what they cannot do.[17] The latter two decisions — the choice of plates and the choice of measurements to take from the plates — depend on what happens in the laboratory, on what turns up on the plates. Once the experimenter sets up the conditions of the experiment, what turns up is beyond his control. Only after can the experimenter reassert control through selection and manipulation.

In the final article Compton reports that he is using data from "the best 14 of a series of 30 plates taken," but the notebooks show him making calculations for 14 numbered plates running from number 15 to number 47.[18] Assuming that plates 1 through 14 served as practice runs, that still leaves three plates unaccounted for, presumably so bad that they do not even count as plates. Although Compton gives no overt definition of what makes the selected plates 'best,' the sixteen deleted plates worst, and the three not plates at all, his notebooks offer two clues about his criteria of selection. First, he tends to select the higher number plates; in fact he records measurements for plates 38, 39, 40, 43, 45, 46, and 47. This suggests that Compton and Simon were still gaining the technical skill to produce plates that clearly revealed the tracks they were interested in. Second, at the bottom of the column of measurements for plate 38 — which in fact was deleted from the article partway through the writing of the draft — the notation "uncertain because too crowded" appears. This notation reinforces the impression that selection was based on how clearly the plates represented and allowed distinctive counts of the data associated with the scattering phenomenon. That is, Compton and Simon were simply looking for clear and distinct tracks.

The tracks on the photographic plates are Compton and Simon's closest glimpse at the scattering phenomenon, and reproductions of some photographic plates are included in the final document to give the readers qualitative visual evidence. How those tracks are interpreted quantitatively, however, depends on a number of manipulations of measurement and calculation. The data tables in Compton's notebook, even in parts of the rough draft of the article, are filled with corrections. These corrections seem all to derive from two incorrect assumptions about the equipment which led to mistaken values for the potential of the x-ray tube and consequently for the energy of the incident radiation. The two causes for error — a warping in a frame and the effect of a condenser — are both carefully noted in the notebook and in the final article. Although on first glance all the corrections appear to be manipulation of the numerical data after the fact, they really only serve to adjust the secondary numerical data to the actual event as occurring in the equipment and recorded on the plates. In addition, although Compton for the most part adheres to Knorr's observation that scientists tend not to report their wrong turnings and errors in the final report[19] (Compton, for example, does not discuss what went wrong in the first fourteen parts nor in the later deleted ones), Compton is very careful to cover this error in both notes and text. His great care, and indeed the great detail with which he reveals this error in the article, suggests that this error is of a different order in that it comes after the laboratory event but seems to change the reality of what happened. To retain the integrity of the data, to make clear that he is constrained by the data and not fiddling with it, he must expose the error of calculation and measurement which leaves the reality of machinery and photograpic plates untouched. Thus the representation of a certain class of error is necessary in the article to keep the relation between laboratory happenings and the report of those happenings as clean as possible. The purpose of exposing the error is not, as Medawar would like,[20] to reveal the psychology of discovery.

The Writing-Up

The previous sections have examined some of the constraints and decisions that determined what the measurements article would look like, but still we do not have a text. Compton must sit down with blank paper in his notebook and create a string of

words, equations, numbers, and graphics to fulfill the possibilities of the constraints. As part of that fulfillment he must represent nature at various levels of mediation: nature as perceived through the literature, as formulated in a problem and hypothesized answer, as inherent in the experimental design and the actual experimental happenings, as represented by the experimental data and the secondary calculations, as interpreted through discussions and conclusions. Thus the article, even while describing the forces that shaped it, is reconstructing views of nature at a number of levels of intellectual and physical mediation. By the convention and logic of the scientific report, however, all these representations must be weighed against the least mediated representation, the data — the photographs and numbers one carries away from the laboratory.

At this point of writing-up the task of the scientist then becomes using language to create these various representations at a level of precision and completeness that adds no further confusion or lack of clarity at any of the levels and that allows an intelligible comparison between the data and the other more mediated representations. When we look at Compton's draft and revisions of the article "Measurements of β-rays Associated with Scattered X-rays," we see indications of just this concern for creating an adequately full and precise representation of nature at several levels of mediation. The larger part of the many changes and corrections he makes as he writes and revises manage the representation of the x-ray-electron interaction, the theory of that interaction, the experimental design and happenings, and the kinds of interpretations and conclusions that can be drawn on the basis of the data.

The following discussion of the drafts and revisions will first present the three major tactics of revision that Compton uses — postponing, extending, and fine tuning — and then will examine epistemological, phenomenological, and social issues raised by the draft and revisions.

Postponing. Postponing is a structural decision made in the course of writing the draft. Four times Compton starts to raise major subjects, then decides he must first reveal some preliminary information. At the end of the opening paragraph in the draft, after only mentioning the photographs, he is about to present a set of reproductions with the phrase, "A typical series of these photographs is shown in figures . . ." Before completing the sentence, however, he strikes it out in order to insert a paragraph spelling out the cloud chamber, x-ray, and photographic equipment. Then in the third paragraph (line 28)[21] he returns to presenting the reproductions of the plates. In the second case, after qualitatively discussing the photographs, Compton begins to raise a major theoretical issue with a new paragraph beginning, "One of the most important questions is whether . . ." He backs away from his direct assault, however, by striking the incomplete sentence and beginning a different paragraph introducing quantitative theory to be matched against empirical data (39). The quantitative material then continues as the main body of the paper. Although it is unclear what important question Compton has in mind, the discussion of all the major questions follows the quantitative presentation. The third case involves the presentation of the first data table. Some time after copying the first two columns of data Compton realized the errors in the potential and energy figures discussed earlier. He apparently then went back to check his equipment and recalculate his figures. He then corrected the figures in the first two columns and copied in the correct figures for column seven, which is calculated from the first two columns. Then in the draft immediately following the table he added a paragraph explaining the error (47-59). In the final paper, however, the table is postponed until after the explanation of the error. In the last case, Compton splits his first draft of the second table, which included data on both maximum range of R-tracks and the distribution of the ranges of the full set of tracks. The latter part of the original table appears later in the article in a slightly different array as Table III. The effect is to allow complete discussion of the issue of maximum range before raising the issue of relative distributions.

In all four cases the postponement is to allow the presentation of additional detailed information prior to the postponed material. In the first and third cases the additional material explains the equipment that produced the postponed data; in the second and fourth cases the inserted material is data logically prior to the postponed material.

Extending. Extensions, giving more information about some item already under discussion, serve to clarify or make precise the item being discussed. For example, "primary beam" is changed to "primary x-ray beam" (5); "photographs" becomes "stereoscopic photographs" (11); "the x-ray tube, enclosed in a lead box" becomes "the Coolidge x-ray tube, enclosed in a heavy lead box" (19-20); and "$\tau + \sigma$" becomes "$\mu = \tau + \sigma$" (80). In a more extensive example, "To calculate the relative number to be expected, we have arranged this expression over the range of wave-lengths used in our experiments," grows in several steps into "To calcuate the relative number of tracks for different relative wave-lengths to be expected, we have arranged this expression by a rough graphical method over the range of wave-lengths used in our experiments." (138-141).

In one case the addition serves to justify a statement. The phrase "in view of the fact that the photographs were stereoscopic" adds a reason to the original phrase which now follows, "it was possible to estimate . . ." (161).

In all the above cases the addition gives detail to the originally mentioned object or event, but in at least three cases the additions redefine the object of concern more precisely. "Track" becomes "length of a given track" (135); "40 tracks" becomes "the directions of 40 tracks" (159); and "short tracks . . . and long tracks" becomes "short tracks (type R) . . . long tracks (type P)" (41). The last example involves a change in epistemic level, to be discussed below.

Fine-tuning. Word substitutions fine tune the language through more specific, correct, or appropriate phasing. Compton achieves greater specificity by such changes as "an" to "the" (110), "the" to "its" (103), and "those" to "the quantity S" (125). More substantive specifications are made in such changes as "acquires" becoming "moves forward with" (109).

In some cases Compton is correcting an outright error, as when he miscopies an equation from a previous article (112), or he incorrectly calls an "expression" an "equation" (147). Elsewhere he must correct an inverted ratio (85), report that there was more than one "condenser" by making the word plural (52), and relabel a "scattering quantum" as a "scattered quantum" (151). More frequently the corrections are more subtle, as when measured values are described as "summarized" rather than "Shown on the following table" (117) or when "C.T.R. Wilson's datum" is changed to "C.T.R. Wilson's result" (119). A repeated subtle error needing frequent correction is referring directly to an object instead of the appropriate quality. Compton in the draft consistently refers to *R* and *P* and *R/P* when discussing the number of electrons but in the final version the notation is consistently changed to N_r, N_p, and N_r/N_p (42, Table I, 75, 83, 88, 96). Related are the wavering from "apparatus" to "chamber" back to "apparatus" (15), the change from "photoelectric absorption coefficient" to "true absorption coefficient" (43), and the revision of "amplitude" to "magnitude" (185).

The last category of fine tuning revisions corrects tactical errors of exposition and thereby modifies slightly the impression of what is being discussed. Compton first begins to describe the maximum frequency "required to" and then switches to "excited by the voltage" (122); a bit later Compton cites a finding "for the number" but then changes that to a finding "that the probability" (134); and a few lines later Compton starts a sentence, "This expression assumes that the electrons all . . ." then recasts the thought changing the subject of the assumption, "This expression assumes that the exciting primary beam . . ." (137). A more clearly consequential example occurs when Compton begins to discuss "the origin of the short" tracks but then changes the focus to "the origin of the two classes of β-rays" (40). Here he changes the topic from one phenomenon to two phenomena in order to prepare for an equation for the ratio of the two later in the sentence. The original singular focus, although not a factual or technical error, was a tactical error in not providing for the continuity of the exposition; the writer must keep in mind what he will discuss in what order, and he must focus the discussion accordingly.

All three types of revision — postponing, extending, and fine-tuning — indicate that the writer is moving through the imprecision and incompleteness of formulations to come to a more focused, accurate representation of what he did, saw, measured, and thought. The language of the original draft is in parts skimpy, fuzzy, misleading, and even wrong, but by struggling with the language the scientist writer can achieve a bit better fit between symbolization and experienced world.

Criteria of adequacy. The symbolic representation of nature is inevitably an approximation in an alien mode; absolute precision and completeness of formulation would be an endless task. Criteria are necessary for a writer to decide whether a linguistic representation is adequate. Compton's draft and revisions offer clues as to his criteria in the instances where he deletes detail or foregoes specificity. Compton seems to follow two criteria: what one can say and what one needs to say — that is, assessments of how finely one knows what one is discussing and of what level of distinction is necessary to carry the particular argument forward.

The rounding off Compton does in Table II shows how these criteria are applied. In the original data tables in the notebook the observed maximum ranges are all measured to the first decimal, but in the transfer of the table to the draft and the consequent revision three observed ranges are rounded off to the nearest integer, in accordance with a prior admission that the observed track lengths "could be estimated probably within 10 or 20 percent" (115-116). That is, the decimals give an appearance of greater accuracy than was probable. Two calculated values, as well, are rounded off to the nearest integer. On these calculated values no error range restrictions apply, but since the degree of statistical correspondence being demonstrated is quite broad (as large as ±3 mm. or 33 per cent of the measured value) the decimals are unnecessary for the demonstration. Compton gives no greater statistical precision than he legitimately can or needs to.

Unneeded specificity is deleted in a number of cases, trivial and substantive. In trivial cases the specification has already been achieved elsewhere in the text as in the deletion of "x-ray" in "primary x-ray beam" (18). In more substantive examples the deleted material raises extraneous theory or inappropriately narrows the discussion. The expression V_c/h is eliminated after the phrase "maximum frequency" because the expression is not used in any of the ensuing calculations (121). The phrases "but radiates uniformly in all directions" (110) and "depending on the direction" (116) are similarly deleted for raising unnecessary qualifications. Another deletion, "mean of the experimentally" from the larger phrase comparing "calculated values with the mean of the experimentally observed relative ranges" (143), emphasizes that the data fit is independent of the voltage and therefore is valid for each of the cases individually rather than only in the mean. Thus the force of an entire set of data is strengthened by the removal of an unnecessarily narrowing qualifier.

The most interesting example of deletion occurs in the description of the photographic equipment (25-27). Compton twice tries to include phrases noting that the full aperture of the lens was employed, but he twice deletes this as unnecessary. Then he twice tries to give positive judgments about the quality of the lenses and plates — "which gave excellent defin . . ." and "very satisfactory." He deleted the first completely and removed the "very" from the second so that the text is left with only the comment that the plates "were found satisfactory." This judgment is all that is needed for the exposition of the experiment. Without a scale of excellence, the more effusive judgments, moreover, do not appear legitimately knowable or supportable to Compton; only the word *satisfactory* carries a criterion of adequacy to the task at hand. Compton's obvious technological pride in the laboratory accomplishment of capturing the scattering phenomenon on photographic plates seems to motivate all four deleted phrases, but he recognizes that such feelings are extraneous to the argument.

Control of Theory, Persona, and Audience

In addition to controlling the more obvious representations of nature, Compton is careful to control the definition of the epistemic level of the discussion, the projection of his persona, and the relationship to the audience. These factors are important to maintain under control, because if improperly treated they could not only obscure the description of nature being proposed, but undermine the purpose of the discourse. By carefully identifying the epistemic level of discussion, Compton is able to identify exactly what he is representing and at what level of mediation. By controlling persona he is able to assert his individual ownership interests, identify where his judgment enters, and limit his intellectual risks, while still keeping attention on what the data and theory suggest. By controlling the relationship to the audience, he serves the reader's convenience,[22] helps the reader follow the argument, and submits himself to the audience's criteria of judgment, again while keeping focus of the article on the formulation and data; his most important task with respect to the audience is to maintain credibility, which is done by remaining responsible to and for the data.

Epistemic level. As part of the process of adjusting language to necessary and possible levels of precision and completeness, Compton carefully assigns each statement to the appropriate epistemic level. That is, items can be represented at different levels of theoretical and empirical mediation. For example, near the beginning of the draft Compton shows uncertainty whether to discuss *rays* or *tracks*. *Rays* of course directly represents the purported object in nature, but *tracks* represents a manifestation of those rays as they pass through a cloud chamber to create vapor trails that are recorded on photographic plates. After a few equivocations and changes, Compton decides to discuss *rays* in the introduction and switch to *tracks* only after the photographic data are introduced. Thereafter the track terminology dominates the rest of the article. Thus Compton indicates that although rays are the object of interest, recorded tracks are all he has to observe and work with.

Even in the discussion of the purported object of nature there is recognition that the discussion is really about objects constructed in the literature. The opening sentence of the published article reads "In recently published papers, C.T.R. Wilson and W. Bothe have shown the existence of a new type of β-ray excited by hard x-rays." The word *new* is added in the draft, so its use is clearly a conscious choice. The word *new*, however, is only appropriate as meaning new in the literature, not new in nature.

Once the linguistic representation of an object is recognized as being a construction of the literature, then it is only appropriate that alternative terms should be used depending on the theoretical context invoked. Thus Compton changes "ray" to "quanta" (89) in accordance with the invocation of quantum theory a few lines earlier. Similarly, Compton begins to write "an [electron]" then corrects this to "a β-particle" (120) in accordance with an earlier switch in discussion from colliding objects to an analysis of ranges of particles. In both cases the changes are not compelled by technical accuracy, but they do help to maintain clear focus on the appropriate theoretical contexts.

Authorial persona. Despite the familiar conjecture that scientists remove themselves from their writing so as to make their work appear less particular and so as to evade epistemological responsibility, Compton maintains an authorial presence in the article. The revisions in some ways enhance this presence and in other ways diminish it. The pattern is that authorial presence is decreased for the prior work, which is merged into the literature of the field, but authorial presence is increased for the current work, for which Compton and his co-worker Simon take responsibility as the thinkers, doers, and owners.

The merging of the individual into the collective of the literature for the scientist's prior work appears in a number of revisions involving self-citations. In the first paragraph of the draft, for example, Compton refers to his previous work "the quantum theory of X-ray scattering proposed by the [author]." Then Compton remembers that Simon is nominally co-authoring the article; he strikes out "the" and substitutes "one of us," to which he appends a footnote to his monograph for the National Research Council. But in the final version the entire phrase "proposed by one of us" is deleted (8-9), suggesting no credit in the text, and a citation to Debye is added to the footnote, sharing credit in the literature and emphasizing that the self-citation is part of a wider literature that is communal. Similar demotions of textual self-reference to footnotes occur at lines 101-103 and 128. In another case the self-reference is removed from the head of the sentence and given a less definitive verb; "Compton and Hubbard give for the . . ." becomes, "If the maximum range of the recoil electrons is S_m, Compton and Hubbard find . . ." (133-134). The most extreme case occurs in the last sentence, when Compton is stressing how well the current work fits with the findings of the literature. The phrase "strong confirmation of the assumptions used by one of us to explain . . ." is shortened by the deletion of the self-reference (187-188); moreover, the self-citing footnote is also eliminated, but a final phrase—the closing phrase of the article—is added: "on the basis of quantum theory" (180). Compton's earlier work is subsumed into a theory which is a fact of the literature transcending individual ownership.

In the previous example, however, even while self-citation is vanishing into the literature, strong reference remains to the authors as conceivers, doers, and owners of the current work. In all versions the last sentence opens with "Our results . . ." (187). Other first person usages remain through all versions to indicate the doing of the work (e.g., "photographs . . . which we have recently made" (11-12), "apparatus used in our work" (15), and "we used a mercury spark" (22)), responsibility for reporting the work (e.g., "In table I we have recorded the results" (47)), intellectual operations (e.g., "we have taken from his data" (78) and "the value of which we used" (81)), ownership of the data (e.g., "in our photographs (157)), the evaluation of the evidence (e.g., "In view, however, of the meager data as yet available on this point, we do not wish to emphasize this correspondence too strongly" (97-99)).

Three revisions, in addition, make the authors' role more explicit. The first two bring out the individual responsibility for the evidence. "Observed in the photographs" becomes "shown in our photographs" (115); "the experimental values" becomes "the observed lengths of the R tracks" (124). The third brings out the evaluative role; "can leave no reasonable doubt" becomes transformed to the more direct "we believe establishes" (83).

Authorial judgments. Even where an author does not use first person to call attention to his evaluative role, he makes many evaluative judgments throughout the article through estimates of the reliability of various claims. Compton sharpens this evaluative role through revisions.

One set of judgments sharpened in revision assigns the way in which a relevant theory specifies a particular phenomenon. In the second sentence of the draft, radiation which has "been ascribed to photoelectrons" gets revised to radiation which has "been identified with photoelectrons," indicating a more specific association. A few lines later Compton flip-flops as to whether a particular interaction is "according to the predictions," "as predicted by," or "in accordance with the predictions of the quantum theory" (8); Compton winds up with the last, and weakest, assumption. As we shall see below, even the title of the article, characterizing the strength of the claim of the whole article, undergoes a similar weakening.

In the above examples the truth value of the claims was not questioned, but only the applicability to specific cases. But the larger set of revisions changes the certainty or character of a claim. "Fact" is weakened to "observation" (96); "suppose" is strengthened to "explained" (92); and a definite "are" wavers to "may be" then regroups to "are often" (68). "A satisfactory agreement" edges up to "a rather satisfactory agreement" (143-144); a "theory" is demoted to an "hypothesis" (154); and the direct identification of "are" weakens to the mediated explanation of "have tracks long enough to determine . . ." (157-158). Finally in the last paragraph an inserted "about" (183) admits that the conclusions rest on approximate evidence.

The most direct judgments are made in the concluding section, and here we see the most adjustment of the strength of claims. In the third from the last paragraph Compton begins to straw strong conclusions from the angles of ejection: "There can be no question but that the electrons ejected . . . ." But he then reconsiders and replaces this strong statement with a sentence about the calculation (173-174). In the next sentence he tries again: "There is undoubtedly . . . ." But he also crosses this out and starts anew with a qualification: "In spite of some discrepancy at the largest angles, the R electrons ejected at small angles undoubtedly have greater energy than those . . ." In the final version, however, even this certainty is excessive, and a weaker judgment is passed to the reader who inspects the data charts: "It will be seen that the observed ranges . . . are . . . in substantial agreement with the theory" (174-177).

Again in the next to the last paragraph, "thus constitutes a strong support of the . . ." becomes the weaker "is thus of special significance" (182). A judgment is again passed to the audience.

Despite these two weakenings the last sentence of the article is strengthened as much as it needs to be to assert the significance of the work. "Our results are thus in . . ." becomes "our results therefore afford a strong confirmation of . . ." (187). Compton thus urges no more than he has to, but does not evade responsibility for judgments. Elsewhere he calls attention to his judgments through italics in intermediate sets of conclusions (82-86 and 128-131).

Audience concerns. The revisions show almost no concern with trying to urge the audience. The only persuasion seems to be that built into the article by the early constraints and early choices that shape the article. If one wishes to study persuasive intent one should look to those early decisions that position the work against previous work, that frame the problem to be addressed, and that determine the kind of evidence to be generated by the experiment; such modes of persuasion are in support of a theoretical position rather than in support of a particular set of results. The only overt attempt to urge the audience in the revisions is the addition of the word "heavy" in front of "lead box" (20) in the appratus description to dispel criticism of contamination through inadequate shielding. All other revisions in anticipation of audience reaction have to do with the conventions and felicity of language: spelling and word form corrections, removing redundancies and excess commas, and rearranging word order and equations for easier reading. Many of these corrections occur between the completion of the revised draft and the publication of the final version. At that time certain small features are also made consistent with the journal style. *Centimeter* is spelled out, but *equation* is abbreviated; the degree symbol is substituted for the word, and the angstrom symbol is simplified by removal of the superior cycle.

Thus, although the audience is accommodated, it is not pushed. The reasons why the audience might want to believe the article are imbedded in the article's structure. A representation of the literature establishing and positioning a problem, an accurate understanding of existing knowledge, the drawing of a question sharply, the appropriateness of the research design, the fit of the results — these are what convince, but these are determined before the writing-up by the early constraints and decisions. The only thing the scientist as writer can control at the writing up stage is the representation of these earlier constraints and choices. In the representation the scientist has some leeway, but the representations to be credible must still

strike the audience as adequate accounts of actual situations. That audience has access to the same literature, has their own formulations of problems, knows what equipment is available and what the equipment can do, can inspect the author's equipment, and can replicate the author's experiment or run other experiments revealing the same phenomenon. In this light we can understand both Compton's throwing certain judgments to the reader under the assumption that the data is clear enough to speak for itself within the theoretical context established by the article, and Compton's efforts in his revisions to make his descriptions as accurate and precise as needed for the argument. His credibility and presuasiveness depend finally on how close a fit his readers find between what he says and what is.

In order to maintain credibility Compton takes great care not to misrepresent his data. Not only is the first person maintained in contexts indicating his responsibility, the author takes explicit responsibility for miscalculations and errors, both through the section added prior to Table I describing the sources of error and through another estimate of error (115-116). This latter discussion of error is difficult for Compton to formulate; he must make several revisions before he can make a reasonable and not misleading formulation of the probable errors. Finally, since the experimental error affecting the data was not discovered until Compton was part way through the draft, a number of corrections had to be made of figures in the text and in the first table.

Text as Object

Through all the constraints and choices we see the gradual emergence of a text — a literary object, separate from, although the consequence of, all that went before. Particularly as the text takes shape in drafting and revision, we can see it take on the quality of an object, open to all the limitations and manipulations of language. But still the text is a linguistic object that takes on the overriding task of the representation of nature.

The act of revision itself treats language as an object. Certain revisions in particular call attention to the text as linguistic construction: the sharpening of the recognition of the obscuring effect of reproduction on photographs (33); the retrospective addition of a phrase because certain terms are needed in an equation on the next line (41); deletions in recognition of later repetitions (90 and 116).

Large organizational shifts call attention both to the manipulable quality of a text and to the gradual construction or emergence of the textual object. The splitting of Table II indicates that Compton is developing an organizational sense of the article that he did not have as he started the draft. Similarly, he did not begin with the subtitles that mark the major divisions of the revised article in mind. The first subtitle in the draft, *"Number of Tracks,"* is clearly an afterthought, squeezed in between lines. But when he reaches the second set of data, Compton realizes that the organization does have major divisions, so he rather emphatically begins the next section with the title *"Ranges of the R Tracks"* on a separate line and centered. By the time he reaches the third of the ultimate divisions, he seems to have gotten used to the organizational structure, and he presents the title *"Angles of Ejection of R. Tracks"* in a more subdued position, on the same line as the new paragraph. This is the position the subtitles take in the printed version.

If the subtitling indicates Compton's increasing awareness of the role of blocks of text, his titling of the whole article indicates his judgment of what the whole text does. The original title in the draft is "Measurements of β-rays Excited by Hard X-rays," but before publication the title was softened to "Measurements of β-rays Associated with Scattered X-rays." The changed title recognizes that the text is not so much concerned with the mechanisms of excitation so much as the association of the rays through measurement and photographs of individual incidents. The text is limited to just an aspect of the phenomenon and just an aspect of Compton's thoughts and convictions about the phenomenon. A text is a limited object.

The abstract. The article's abstract serves as one further step in turning the article into an object, for the abstract considers the article as a whole and then makes a representation of it. In this regard the point at which Compton decides to write the abstract is a good indicator of when he gains a grasp of the whole text. The draft of the abstract appears about two-thirds the way through the draft of the main text, at a spot corresponding to line 142 of the published version. The earlier part of the abstract draft, in addition, contains the kinds of numerical errors that Compton was not aware of until he reached Table I (59). These facts indicate that Compton probably began the abstract when he was part way into the article; he apparently turned to a blank page where he thought the main draft would end. He did not have a grasp of the whole when he began the article and had to wait until he saw what he had written before he wrote the

abstract; nonetheless, he felt he needed to write the abstract before completing the article, in order to articulate his sense of the whole and to keep the later parts logically and structurally consistent.

Even in the abstract itself he seems to need to recapitulate the entire argument before summarizing the conclusion. He reduces the summary of the data to a one-sentence statement recounting the main topics: "Measurements were made of the maximum range, the relative number of different ranges, the relative number ejected at different angles, and the relative ranges of the R tracks ejected at different angles." This sentence does not find its way into the published abstract, but rather seems more for Compton's own benefit.

Furthermore, the draft of the abstract is not complete on the notebook pages alloted it, suggesting that Compton returned to the main article before finishing the abstract and did not leave enough blank space for the completion of the abstract. The abstract draft breaks off in mid-sentence at the bottom of a page; the next page continues with the main text in mid-sentence. If the abstract did get written in stages coordinated with the writing of the main text, that correlation would further emphasize the interaction between the gradual creation of the text and the growing perception and command of the text as an object.

The specific content of the abstract and its revisions further reveal Compton's perception of what kind of object the text is. The substantial discussions in the main text of the background literature and the experimental apparatus become only sketchy mentions via secondary phrases in the first few sentences of the abstract. The sentences are more concerned with the data and findings; the grammatical subjects are reserved for "photographs," "kinds of tracks," and "ratio." Moreover, the problem addressed in the paper, "a more quantitative study of the properties of these rays" (14), does not receive explicit mention in the abstract.

The first eight of the nine sentences of the abstract are devoted to reporting the findings in some statistical detail. The organization of sentences three through eight follows exactly the structure of the body of the paper reporting the data and findings, with two sentences devoted to each of the topics announced in the subtitles of the paper. The conclusions are reported in the last sentence of the abstract; however, that sentence is very long, about eighty words, and manages to incorporate almost all the substance of the final two paragraphs of the full paper. The one sentence summary in fact incorporates verbatim many of the key phrases of the full version.

The abstract, therefore, focuses on the outcome of the experiment rather than on the background, formulation of the problem, or the experimental design. Nor does the abstract try to recapture a coherent argument, which would require more emphasis on theory and context. The emphasis is entirely on what can be formulated about the out-there physical phenomenon as a result of the experiment.

The revisions of the abstract draft emphasize this focus. Specifying phrases are added about the observed phenomenon, and excess theory and reference to calculations are eliminated. Finally, the original terse summary of conclusions is greatly expanded to incorporate almost all the substance of the full conclusions, as previously noted.

Conclusions

One must always be cautious about generalizing from a single case. The following conclusions, therefore, stay close to the particular case. These conclusions, nonetheless, are more generally suggestive for two reasons. First, although revealing a complex social, psychological, and intellectual dynamic of scientific formulation, this case gives some grounds for traditional empiricist simplifications. Second, this case suggests a mechanism whereby scientific discourse can become accountable to nature; even more, the mechanism subordinates other social and personal accountabilities to the accountability to nature. If such a mechanism appears in one case, it (or a similar mechanism) is likely to appear in others. This paper thus opens up a major area of analysis of scientific discourse — an area that is central to science's understanding of itself and its chosen tasks, yet an area which has been ignored in recent studies of scientific discourse. I will end, however, by suggesting some of the ways in which this particular case may be limited, as may be all detailed analyses of scientific discourse. The differences among such detailed studies open up several new questions for investigation.

A.H. Compton, as all authors do, chooses the words that go on the page and thereby creates a statement — a text, a linguistic object — that did not exist before. But Compton's choices are severely constrained by contextual forces, directed by procedures of scientific argumentation, and motivated by his personal commitment to record his claims and data as accurately as he is able. Some of the contextual contraints are active (in

Fleck's terminology) in that they reflect the structure of the scientific community, the thought style and expressive habits of the period, the social position and interests of the investigator within the scientific community, the research program and theory commitments of the scientist, and the nature of the challenges to prior formulations of theory.

Within this context Compton has some freedom in choosing what claims to advance, in formulating or reformulating those claims, and in designing experiments or other means of advancing those claims. It is at this point that Compton seems to have the most leeway to frame his work strategically, positioning it against other claims and challenges. It is at this stage of basic positioning, I believe, that we should look for the locus of persuasive strategy rather than at the actual writing up stage with its narrower manipulation of language. At this stage Compton decided what the real issues in the problem area were and how he could address them in the way most persuasive to his colleagues.

These strategic choices, nonetheless, were subject to constraints, but the constraints were passive. Compton could not violate the bulk of previously gathered data (although he could actively reinterpret or offer alternate explanations for the data.) He could not make equipment do what it could not do, and he could not control what data ultimately got recorded on the photographic plates. Moreover, given the canons of scientific argumentation which Compton observed, the center of the persuasive strategy was the active search for passive constraints. Compton bolstered his original discovery claim by developing a new source of data; he answered challenges by finding specific refuting data; and he advanced his own career by revealing more about the phenomenon and developing techniques for looking more intimately into nature.

Once the experiment has run its course, Compton could only choose to publish or not publish the results. Having chosen publication Compton is committed to presenting his theory and results as clearly, accurately, and precisely as the material and language allow. This precision, accuracy, and clarity in part serve the persuasive intention by identifying the tightness of fit among his claim, experimental procedures, and observed nature; in part they protect him from criticism of fuzziness or fraudulence (note particularly his careful revelations about the necessary recalculations to preserve the integrity of the data).

But the revisions are so careful on even such apparently inconsequential matters as his estimate of the quality of the photographic technique or the choice of "the" over "an" that they reveal a deeply internalized commitment to the best possible representation of the material within his theoretical, experimental, and linguistic scope.

Since there is no guarantee of an essential link between the objects of nature and the words and equations scientists formulate to describe those objects and their behavior, the nonfiction created by Compton, or any other scientist, cannot be taken as absolute, a transparent and congruent presentation of nature as it is. The formulating mechanisms suggested above, however, do provide a means by which Compton and other scientists may improve their formulations, holding those formulations more closely accountable to nature as it is perceived through the thought style of the scientist's thought collective.

It would, however, be premature to suggest how general the mechanisms described above actually are for several reasons beyond the normal cautions of the case study: (1) The fact that the Compton material was among the very few sets of rough drafts of writing in physics that I was able to locate may indicate that Compton was idiosyncratic among physicists in the seriousness with which he took writing. (2) The idiosyncratic care for language may be heightened by the high stakes involved with Compton's claims and reputation at this point. (3) In other scientific work of more directly practical consequence, other accountabilities may shape the discourse in different directions. (See, for example, Knorr-Cetina's analyses of writing in the area of protein resources, closely linked the pressing social needs of nutrition.[23]) (4) The character of science, particularly the canons of scientific argumentation, appears to change through time, discipline, and situation. Yearley, analyzing a text in early nineteenth century geology, finds a very different mode of argumentation and a very different set of authorial commitments than found here[24]; further, Gilbert and Mulkay, working with a highly competitive field in contemporary biochemistry find strong evidence of interest laden distortion.[25]

Such cautions suggest the need for (1) studies of general writing practices among contemporary scientists, including investigations of whether writing practices change with the anticipated importance, anticipated controversy, or the reputation of the author; (2) comparisons of scientific writing in different fields with different relations to wider social needs; and (3) studies of the changing nature of scientific discourse, with particular concern for the emergence of contemporary canons of scientific discourse.[26]

P/T

Notes

I wish to thank E. Davenport, J. Dore, N. Mullins, C. Piltch, R. Stuewer, S. Weart, and H. Zuckerman and the referees for *Pre/Text* for their helpful comments, suggestions, and corrections as this paper passed through various forms. I especially wish to thank the librarians at the Center for the History of Physics, American Institute of Physics, New York, for their many kindnesses. An earlier version of this paper was delivered to the Society for the Social Studies of Science (Atlanta, 1981) and the New York Circle for the Theory of Literature and Criticism.

[1]N. Gilbert, "The Transformation of Research Findings into Scientific Knowledge," *Social Studies of Science,* 6 (1976), 281-306; N. Gilbert, "Referencing as Persuasion," *Social Studies of Science,* 7 (1977), 113-122; N. Gilbert and N. Mulkay, "Contexts of Scientific Discourse: Social Accounting in Experimental Papers," *Sociology of the Sciences Yearbook,* 1980, 169-294; N. Gilbert and M. Mulkay, "Experiments are the Key" and "Warranting Scientific Belief," unpublished papers; M. Mulkay and G.N. Gilbert, "Joking Apart: Some Recommendations Concerning the Analysis of Scientific Culture," *Social Studies of Science,* 12 (1982), 585-614; J. Law and R.J. Williams, "Putting Facts Together: A Study of Scientific Persuasion," *Social Studies of Science,* 12 (1982), 535-558; K. Knorr-Cetina, *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon, 1981); K. Knorr, "Producing and Reproducing Knowledge: Descriptive or Constructive?" *Social Science Information* 16 (1977), 669-696; K. Knorr, "Tinkering Toward Success: Prelude to a Theory of Scientific Practice," *Theory and Society,* 8 (1979), 347-376; K. Knorr and D. Knorr, "From Scenes to Scripts: On the Relationship between Laboratory Research and Published Paper in Science," Institute for Advanced Studies, Vienna, Research Memorandum No. 132 (1978); B. Latour and S. Woolgar, *Laboratory Life* (Beverly Hills: Sage, 1979); S. Woolgar, "Discovery: Logic and Sequence in a Scientific Text," *Sociology of the Sciences Yearbook,* 1980, 239-268; S. Woolgar, "Writing an Intellectual History of Scientific Development: The Use of Discovery Accounts," *Social Studies of Science,* 6 (1976), 395-422; S. Yearley, "Textual Persuasion: The Social Accounting in the Construction of Scientific Arguments," *Philosophy of the Social Sciences,* 11 (1981), 409-435.

[2]J.M. Cattell and J. Cattell, Eds., *American Men of Science,* 4th edition (New York: Science Press, 1927), p. 897.

[3]Since a number of the revisions that appear in the published article are not marked in the revised draft, an editor may have suggested some of the changes. Compton, however, would have had to approve any suggestions. I am therefore accepting the simplifying assumption that Compton is responsible for all revisions.

[4]A.H. Compton, "A Quantum Theory of the Scattering of X-Rays by Light Elements," *Physical Review,* 21 (1923), 483-502.

[5]The current view of Compton's work neglects his theoretical concern in developing an account of x-ray scattering consistent with electrodynamic theory in favor of an empirical result that was originally subordinate to theoretical issues. This interpretive shift began quite early. Compton's article appeared in volume 21 of *Physical Review.* Of the citations that appeared through volume 25 of that journal (a span of two years), excluding self-citations, nine appear in contexts that refer to his theory, and only one is concerned primarily with his empirical results. Of the citations in volumes 26 through 29, however, two are primarily theoretical, three are empirical, and one is mixed. Given the progress of quantum theory during that period and since and the consequent change of the importance of Compton's work, such a reinterpretation makes sense as part of the historically changing codification of the literature of a scientific field. But such reinterpretation based on current scientific belief in effect rewrites the original article.

I drew the citations from *A Citation Index for Physics: 1920-1929* (Philadelphia: Institute for Scientific Information, 1980); incidentally, Compton's "Quantum Theory" article was the most cited article in physics during the decade.

Theory citations: 22, 283; 23, 122; 23, 135; 23, 316; 24, 179; 24, 591; 25, 314; 25, 444; 25, 723; 26, 435; 28, 875.

Experiment citations: 25, 193; 26, 299; 26, 657, 29, 758.

Mixed citation: 26, 691.

[6]The importance of Compton's research program for the shape of his argument is made evident by a comparison to Debye's paper proposing a similar quantum theory of x-ray scattering, that might be taken as a case of simultaneous discovery. (P. Debye, "Zerstreuung von Rontgenstrahlen und Quantentheorie," *Physikalische Zeitschrift,* 24 (1923), 161-166.) Debye was not associated with the x-ray problem area, but rather was deeply committed to the quantum theory and its elaboration. Consequently, Debye's paper presents an extension of quantum theory that explains data anomalous to classical electrodynamic theory. Rather than presenting the progress and general types of difficulties run into by classical theory (as Compton does), Debye points to specific data anomalies. The derivation of the equations then follows, not as a proposed theory to be tested as in Compton's paper, but as a direct answer to difficulties. For Debye, quantum theory already stands, and this is only one more demonstration of its power; for Compton quantum theory is a last explanatory resource to be tested only after all classical explanations have been exhausted.

[7]The full history of Compton's discovery, the challenges, and Compton's responses are recounted in R. Stuewer, *The Compton Effect* (New York: Science History, 1975). Compton's chief responses to challenges appear in the following articles: A.H. Compton, "Scattering of X-ray Quanta and the J Phenomena," *Nature,* 113 (1924), 160-61; A.H. Compton, "Absorption Measurements of the Change of Wave-length Accompanying the Scattering of X-Rays," *Philosophical Magazine,* 46 (1923), 897-911; A.H. Compton, "The Spectrum of Scattered X-rays," *Physical Review,* 22 (1923), 409-413; A.H. Compton and Y.H. Woo, "The Wave-Length of Molybdenum Koc Rays when Scattered by Light Elements," *Proceedings of the National Academy of Sciences,* 10 (1924), 271-273; A.H. Compton and J.A. Bearden, "The Effect of a Surrounding Box on the Spectrum of Scattered X-Rays," *Proceedings of the National Academy of Sciences,* 11 (1925), 117-119.

[8]C.T.R. Wilson, "Investigations on X-Rays and β-rays by the Cloud Method. Part I.--X-Rays," *Proceedings of the Royal Society,* 104 (1923), 1-24; W. Bothe, "Über eine neu Sekundärstrahlung der Röntgenstrahlen," *Zeitschrift für Physik,* 16 (1923), 319-210, and 20 (1924), 237-255.

[9]A.H. Compton, "Recoil of Electrons from Scattered X-Rays," *Nature,* 112 (1923), 435.

[10]A.H. Compton and J.C. Hubbard, "The Recoil of Electrons from Scattered X-Rays," *Physical Review,* 23 (1924), 439-456; A.H. Compton, "The Scattering of X-rays," *Journal of the Franklin Institute,* 198 (1924), 57-72; A.H. Compton, "A General Quantum Theory of the Wave-length of Scattered X-rays," *Physical Review,* 24 (1924), 168-176.

[11]A.H. Compton and A.W. Simon, "Measurements of β-Rays Associated with Scattered X-Rays," *Physical Review,* 25 (1925), 306.

[12]*Ibid.,* p. 307.

[13]L. Fleck, *Genesis and Development of a Scientific Fact,* tr. F. Bradley and T. Trenn (Chicago: Univ. of Chicago Press, 1979) discusses how active and passive resistances give rise to formulations taken to be facts by a thought collective. These formulations are developed and expressed within the stylized terms of the thought collective.

[14]N. Bohr, H.A. Kramers, and J.C. Slater, "The Quantum Theory of Radiation," *Philosophical Magazine,* 47 (1924), 785-802.

[15]A.H. Compton and A.W. Simon, "Directed Quanta of Scattered X-Rays," *Physical Review,* 26 (1925), 289-299.

[16]Arthur H. Compton, *Notebook III,* pp. 20-41.

[17]Latour and Woolgar, *Laboratory Life, op. cit.* note 1, citing G. Bachelard, *Le matérialisme rationnel* (Paris: P.U.F., 1953), discuss laboratory equipment as a reification of theory. This idea is intriguing, but it must be kept in mind that no matter how fully suggested by theory, the equipment must accord with the functioning of nature to work; in this way the equipment is as much a test of theory as reification of theory.

[18]*Ibid.,* pp. 49-52. On the bottom right hand corner of page 51 there is a boxed off set of data that is unlabelled that may represent a fifteenth plate; if so this would compensate for the apparent discrepancy caused by the later deletion of plate 38.

[19]Knorr, "Tinkering Toward Success" and Knorr and Knorr, "From Scenes to Scripts," *op. cit.* note 1.

[20]P.B. Medawar, "Is the Scientific Paper Fraudulent?" *Saturday Review*, 1 August 1964, 42-43.

[21]The line references that continue to the end of the paper refer to the final published version of the 'Measurements' article, reproduced and given line reference numbers in the appendix. Draft and revisions appear in Notebook III, pp. 59-75.

[22]Such interest in the audience's convenience is the basis of the research reviewed in M. Ennis, "The Design and Presentation of Informational Material," *Journal of Research Communication Studies*, 2 (1980), 67-82.

[23]"From Scenes to Scripts" and *The Manufacture of Knowledge*, *op. cit.* note 1.

[24]*op. cit.* note 1.

[25]"Contexts of Scientific Discourse," *op. cit.* note 1.

[26]Recent contributions toward a history of the scientific paper are J. Paradis, "Historical Aspects of Language Reform in the Sciences: 1620-1840" and J. Stephens, "Style as Therapy in Renaissance Science" both in *New Essays in Technical and Scientific Communication: Theory, Research, and Criticism*, ed. Anderson, Miller, Brockmann (Farmingdale, NY: Baywood, 1983); and C. Bazerman, "Modern Evolution of the Experimental Report in Physics: Spectroscopic Articles in *Physical Review*, 1893-1980," *Social Studies of Science*, 14 (1984), 163-196.

Appendix

MEASUREMENTS OF β-RAYS ASSOCIATED WITH SCATTERED X-RAYS

By Arthur H. Compton and Alfred W. Simon

Abstract

Stereoscopic photographs of beta-ray tracks excited by strongly filtered x-rays in moist air have been taken by the Wilson cloud expansion method. In accord with earlier observations by Wilson and Bothe, two distinct types of tracks are found, a longer and a shorter type, which we call P and R tracks, respectively. Using x-rays varying in effective wave-length from about 0.7 to 0.13 A, the ratio of the observed number of R to that of P tracks varies with decreasing wave-length from 0.10 to 72, while the ratio of the x-ray energy dissipated by scattering to that absorbed (photo-electrically) varies from 0.27 to 32. This correspondence indicates that about 1 R track is produced for every quantum of scattered x-radiation, assuming one P track is produced by each quantum of absorbed x-radiation. The *ranges* of the observed R tracks increase roughly as the 4th power of the frequency, the maximum length for 0.13 A being 2.4 cm at atmospheric pressure. About half of the tracks, however, had less than 0.2 of the maximum range. As to *angular distribution*, of 40 R tracks produced by very hard x-rays (111 kv), 13 were ejected at between 0 and 30° with the incident beam, 16 at between 30° and 60°, 11 at between 60° and 90° and none at a greater angle than 90°. The R electrons ejected at small angles were on the average of much greater range than those ejected at larger angles. These results agree closely in every detail with the theoretical predictions made by Compton and Hubbard, and the fact that in comparing observed and calculated values, no arbitrary constant is assumed, makes this evidence particularly strong that the assumptions of the theory are correct, and that whenever a quantum of x-radiation is scattered, an R electron is ejected which possesses a momentum which is the vector difference between that of the incident and that of the scattered x-ray quantum.

In recently published papers, C. T. R. Wilson[1] and W. Bothe[2] have shown the existence of a new type of β-ray excited by hard x-rays. The range of these new rays is much shorter than that of those which have been identified with photo-electrons. Moreover, they are found to move in the direction of the primary x-ray beam, whereas the photo-electrons move nearly at right angles to this beam.[3] Wilson, and later Bothe,[4] have both ascribed these new β-rays to electrons which recoil from scattered x-ray quanta in accordance with the predictions of the quantum theory

[1] C. T. R. Wilson, Proc. Roy. Soc. A **104**, 1 (1923)
[2] W. Bothe, Zeits. f. Phys. **16**, 319 (1923)
[3] See, e.g., F. W. Bubb, Phys. Rev. **23**, 137 (1924)
[4] W. Bothe, Zeits. f. Phys. **20**, 237 (1923)

of x-ray scattering.[5] In support of this view, they have shown that the direction of these rays is right, and that their range is of the proper order of magnitude. The present paper describes stereoscopic photographs of these new rays which we have recently made by Wilson's cloud expansion method. In taking the pictures, sufficiently hard x-rays were used to make possible a more quantitative study of the properties of these rays.

The cloud expansion apparatus used in our work was patterned closely after Wilson's well-known instrument except that all parts other than the glass cloud chamber itself were made of brass. The timing was done by a single pendulum, which carried a slit past the primary beam and actuated the various levers through electric contacts. The Coolidge x-ray tube, enclosed in a heavy lead box, was excited by a transformer and kenotron rectifiers capable of supplying 280 peak kilovolts. For illumination we used a mercury spark, similar to that of Wilson, through which discharged a 0.1 microfarad condenser charged by a separate transformer and kenotron to about 40 kv. The photographs were made by an "Ontoscope" stereoscopic camera, equipped with Zeiss Tessar $f/4.5$ lenses of 5.5 cm. focal length. Eastman "Speedway" plates (45×107 mm) were found satisfactory.

A typical series of the photographs[6] obtained are reproduced in Plate I, (a) to (f), which show the progressive change in appearance of the tracks as the potential across the x-ray tube is increased from about 21 to about 111 kv.

Especially in view of the fact that the original photographs are stereoscopic, the negatives of course show much more detail than do the reproductions. These suffice to show, however, the two types of tracks, the growth of the short tracks with potential, and the fact that while the long tracks are most numerous for the soft x-rays, the short tracks are most in evidence when hard rays are used. These results are in complete accord with Wilson's observations.

Number of tracks. It has been shown[7] that if the above interpretation of the origin of the two classes of β rays is correct, the ratio of the number of short tracks (type R) to that of long tracks (type P) should be

$$N_R/N_P=\sigma/\tau \qquad (1)$$

where σ is the scattering coefficient, and τ the true absorption coefficient of the x-rays in air; for σ is proportional to the number of scattered

[5] A. H. Compton, Bulletin Nat. Res. Council, No. 20, p. 19 (1922); and P. Debye, Phys. Zeits. (Apr. 15, 1923)

[6] These photographs were shown at the Toronto meeting of the British Association in August 1924.

[7] A. H. Compton and J. C. Hubbard, Phys. Rev. **23**, 448 (1924)

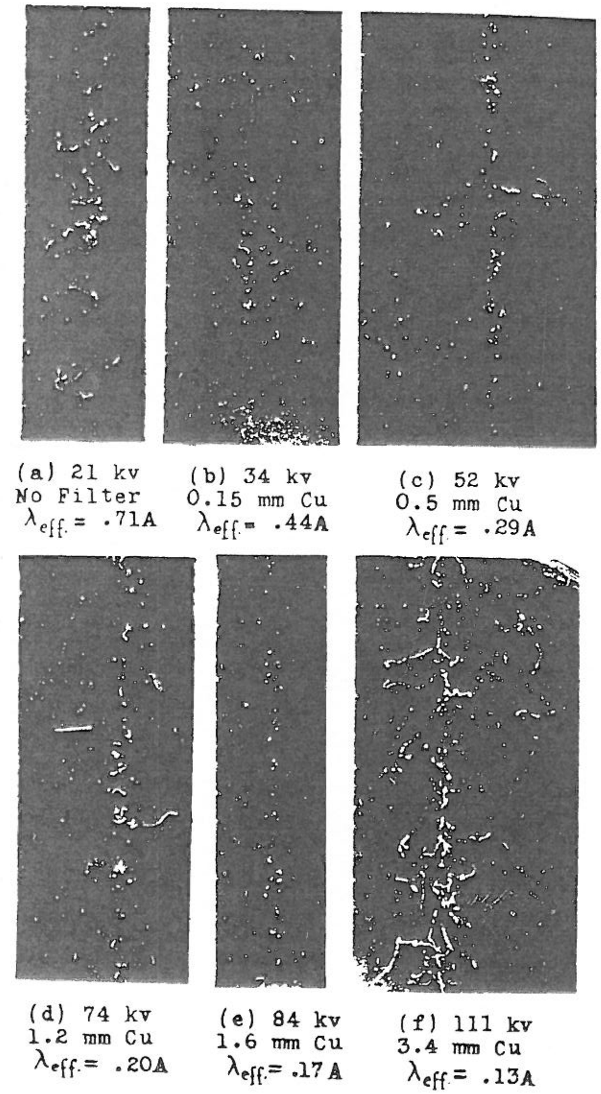

Plate I. The x-rays pass from top to bottom. In addition to the copper filter, they traverse glass walls 4 mm thick. For the short waves the shorter (R) tracks increase rapidly in length and number. Thus while in (a) nearly all are P tracks, in (f) nearly all are R tracks.

quanta, and τ to the number of quanta spent in exciting photo-electrons, per centimeter path of the x-rays through the air.

In Table I we have recorded the results of the examination of the best 14 of a series of 30 plates taken at different potentials. The potentials given in column 1 of this table are based on measurements with a sphere gap. The potential measurements required corrections due to a slight warping of the frame holding the spheres, and to the lowering of the line voltage when the condenser was charged for the illuminating spark. The latter error was eliminated in the later photographs, at 34, 21, and 74 kv, and the former error was corrected by a subsequent measurement of the sphere gap distances, checked by a measurement of the lengths of the P tracks obtained at the lowest potential. The probable errors of potential measurements are thus unfortunately large, amounting to perhaps 10 percent in every case except that of 74 kv, which is probably accurate to within 5 per cent.

TABLE I

Number of tracks of types R and P.

Potential	Effective wave-length	Total tracks N	R tracks N_R	P tracks N_P	N_R/N_P	σ/τ
21kv	.71A	58	5	49	0.10	0.27
34	.44	24	10	11	0.9	1.2
52	.29	46	33	12	2.7	3.8
74	.20	84	74	8	9	10
84	.17	73	68	4	17	17
111	.13	79	72	1	72	32

The effective wave-lengths as given in column 2 are the centers of gravity of the spectral energy distribution curves after taking into account the effect of the filters employed. Because of the strong filtering, the band of wave-lengths present in each case is narrow, and the effective wave-length is known nearly as closely as the applied potential.

All the tracks originating in the path of the primary beam are recorded in column 3. Of these, the nature of some was uncertain. At the lower voltages it was difficult to distinguish the R tracks from the "sphere" tracks which Wilson has shown are often produced near the origin of a β-ray track by the fluorescent K rays from the oxygen or nitrogen atoms from which the ray is ejected. At the highest voltage the length of some of the R tracks is so great as to make it difficult to distinguish them from the P tracks. The numbers of R and P tracks shown in columns 4 and 5 are those of the tracks whose nature could be recognized with considerable certainty, the uncertain ones not being counted. This procedure probably

makes the values of N_R/N_P in column 6 somewhat too small for the lower potentials and somewhat too great for the higher potentials.

The values of σ and τ given in column 7 are calculated from Hewlett's measurements[8] of the absorption of x-rays in oxygen and nitrogen. We have taken from his data the value of τ for 1 A to be 1.93 for air, and to vary as λ^3. The difference between the observed value of $\mu=\tau+\sigma$ and this value of τ gives the value of σ which we used.

The surprisingly close agreement between the observed values of N_P/N_R and the values of σ/τ we believe establishes the fact that the *R tracks are associated with the scattering of x-rays.* In view of the evidence that each truly absorbed quantum liberates a photo-electron or P track,[9] the equality of these ratios indicates that *for each quantum of scattered x-rays about one R track is produced.*

The fact that for the greater wave-lengths the ratio N_R/N_P seems to be smaller than σ/τ may mean that not all of the scattered quanta have R tracks associated with them. This would be in accord with the interpretation which has been given of the spectrum of scattered x-rays. The modified line has been explained by assuming the existence of a recoil electron, and the unmodified line as occurring when the scattering of a quantum results in no recoil electron. On this view the fact that the unmodified line is relatively stronger for the greater wave-lengths goes hand in hand with the observation that N_R/N_P is less than σ/τ for the greater wave-lengths. In view, however, of the meager data as yet available on this point, we do not wish to emphasize this correspondence too strongly.

Ranges of the R tracks. The range of the recoil electrons has been calculated on the basis of two alternative assumptions.[10] First, assuming that the electron recoils from a quantum scattered at a definite angle, its energy is found to be

$$E=h\nu\frac{2\alpha\cos^2\theta}{(1+\alpha)^2-\alpha^2\cos^2\theta}, \qquad (2)$$

where $\alpha=h\nu/mc^2$, and θ is the angle between the primary x-ray beam and the direction of the electron's motion. This energy is a maximum when $\theta=0$, and is then,

$$E_m=h\nu\frac{2\alpha}{1+2\alpha}. \qquad (3)$$

[8] C. W. Hewlett, Phys. Rev. **17**, 284 (1921)

[9] See, e. g., A. H. Compton, Bull. Nat. Res. Council No. 20, p. 29, 1922

[10] See Compton and Hubbard, loc. cit.[7]

The second assumption is that the R electron moves forward with the momentum of the incident x-ray quantum. In this case the energy acquired is

$$E' = h\nu \cdot \frac{1}{2}\frac{\alpha}{1+2\alpha}(1-\tfrac{1}{4}\alpha^2+\ \cdot\ \cdot\ \cdot\ ) . \qquad (4)$$

Eq. (3) was found to agree considerably better than Eq. (4) with Wilson's experimental results.

The lengths of the tracks shown on our photographs could be estimated probably within 10 or 20 per cent. These measured values, reduced to a final pressure of 1 atmosphere, are summarized in Table II. In column 2 are recorded the lengths of the longest tracks observed at each potential. S_m is the range calculated from Eq. 3, using C. T. R. Wilson's result[1] that the range of a β-particle in air is $V^2/44$ mm, where V is the potential in kilovolts required to give the particle its initial velocity, and the frequency ν employed is the maximum frequency excited by the voltage applied to the x-ray tube. S' is similarly calculated from Eq. (4).

TABLE II

Maximum lengths of R tracks.

Potential	Observed	Calc. (S_m)	Calc. (S')
21kv	0mm	0.06mm	0.004mm
34	0	0.3	0.02
52	2.5	1.8	0.1
74	6	6	0.4
88	9	12	0.7
111	24	25	1.5

It is evident that the observed lengths of the R tracks are not in accord with the quantity S' calculated from Eq. (4). They are, however, in very satisfactory agreement with the values of S_m given by Eq. (3). This result agrees with the conclusion drawn from Wilson's data,[11] but is now based upon more precise measurements. It follows that *the momentum acquired by an R particle* is not merely that of the incident quantum, but *is the vector difference between the momentum of the incident and that of the scattered quanta.*[12]

This conclusion is supported by a study of the relative number of tracks having different ranges. If the maximum range of the recoil electrons is S_m, Compton and Hubbard find[7] that the probability that the length of a given track will be S is proportional to

$$(2\sqrt{S/S_m}+\sqrt{S_m/S}-2) . \qquad (5)$$

[11] Compton and Hubbard, loc. cit.,[7] p. 449.

[12] That this is true for the β-rays excited by γ-rays has been shown in a similar manner by D. Skobeltzyn, Zeits. f. Phys. **28**, 278 (1924).

This expression assumes that the exciting primary beam has a definite wave-length. To calculate the relative number of tracks for different relative lengths to be expected, we have averaged this expression by a rough graphical method over the range of wave-lengths used in our experiments. These calculated values are given in the last column of Table III, for the relative ranges designated in column 1. A comparison of these

TABLE III

Relative lengths of R tracks.

Range of S/S_M	Per cent of R tracks within this range: 52kv	74kv	88kv	111kv	Mean	Calc.
0- .2	44	66	60	54	56	53
.2- .4	34	20	26	32	28	22
.4- .6	19	8	4	8	10	14
.6- .8	0	3	5	3	3	8
.8-1.0	3	3	5	3	3	3

calculated values with the observed relative ranges shows a rather satisfactory agreement throughout. It will be noted further that the probabilities of tracks of different relative ranges is found to be about the same for x-rays excited at different potentials. This is in accord with the theoretical expression (5) for the probability, which is independent of the wave-length of the x-rays employed.

Angles of ejection of R tracks. On the view that the initial momentum of an R electron is the vector difference between the momenta of the incident and the scattered quantum, it is clear that these electrons should start at some angle between 0 and 90° with the primary beam. The probability that a given track will start between the angles θ_1 and θ_2 is on this hypothesis,[13]

$$\int_{\theta_1}^{\theta_2} P_\theta d\theta = 3ab\int_{\theta_1}^{\theta_2}\frac{a^2\tan^4\theta+b^2}{(a\tan^2\theta+b)^4}\frac{\sin\theta}{\cos^3\theta}d\theta , \qquad (6)$$

where $a=(1+h\nu/mc^2)^2$, and $b=(1+2h\nu/mc^2)$.

In our photographs only those taken at 111 kilovolts have tracks long enough to determine the initial direction with sufficient accuracy to make a reliable test of this expression. In all, the directions of 40 tracks were estimated, with the results tabulated in the second column of Table IV. In view of the fact that the photographs were stereoscopic, it was possible to estimate the angles in a vertical plane roughly, though not closer perhaps than within 10 or 15°. The values in the third column are calculated from Eq. (6). It is especially to be noted that, in accord with the

[13] See Compton and Hubbard, loc. cit.,[7] Eq. (14).

theory, no R tracks are found which start at an angle greater than 90° with the primary x-ray beam. In view of the small number of tracks observed and the approximate character of the angular estimates, the agreement between the two sets of values is as close as could be expected.

A more searching test of the assumption that the R tracks are electrons which have recoiled from scattered quanta is a study of the relative ranges of the tracks starting at different angles. (See columns 4 and 5 of Table IV.) The calculated ranges in column 5 are based on Eq. (2) for

TABLE IV

Number and range of R tracks at different angles, for 111 kv x-rays.

Angle of emission	Per cent of total number (obs.)	(calc.)	Average range (obs.)	(calc.)
0°-30°	34	28	9 mm	11 mm
30°-60°	39	50	4	4
60°-90°	27	22	0.9	0.3

the energy at different angles. In this calculation the effective wave-length, as estimated in connection with Table I, is employed. It will be seen that the observed ranges of the tracks ejected at small angles are much greater than that of those ejected at large angles, in substantial agreement with the theory.

It is worth calling particular attention to the fact that in comparing the theoretical and experimental values in these tables, no arbitrary constants have been employed. The complete accord between the predictions of the theory and the observed number, range, and angles of emission of the R tracks is thus of especial significance.

The evidence is thus very strong that there is about one R track or recoil electron associated with each quantum of scattered radiation, and that this electron possesses, both in direction and magnitude, the vector difference of momentum between the incident and the scattered x-ray quantum. Our results therefore afford a strong confirmation of the assumptions used to explain the change in wave-length of x-rays due to scattering, on the basis of the quantum theory.

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November 15, 1924.