Optical Resource Letter on Radiometry

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These Optical Resource Letters are patterned after the materials that have been developed by the AAPT Committee on Resource Letters and previously published in the *American Journal of Physics.* Since they contain information of direct interest to most teachers of physics, we are pleased to have the permission of the *Journal of the Optical Society of America* to reprint them in AJP. The purpose is to provide, in an important field of optics, briefly annotated references that should be of value to teachers, researchers, engineers, and technicians interested in the subject area. No claim is made for completeness or exhaustiveness of coverage; rather, it is hoped that the references quoted will be helpful in themselves and will be representative, or at least suggestive, of the broad literature on this subject. The letter E following an item number indicates that the reference is on a more-or-less elementary level; the letter A indicates an advanced level.

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Radiometry is seldom taught or pursued by and for itself; usually this is done in connection with some other subject (e.g., astrophysics or meteorology), or attention is confined to just one of its major subdivisions (e.g., photometry, illumination engineering, or optical pyrometry). Those who conduct radiometric studies and publish their results tend to group themselves according to these categories, usually with poor communication between different groups. Each group tends to publish in its own journals and to develop its own scheme of concepts, terminology, symbols, sacred cows, and jargon and thus further discourages intergroup communication.

In these circumstances, not only is the disclaimer of completeness for this resource letter particularly apt, but it is also extremely difficult, if not impossible, even to achieve representative coverage of the field or, in fact, to determine what is truly representative of radiometry as a whole. Accordingly, the first person is used occasionally, as a reminder that it is radiometry as seen through the author's eyes that is being presented.

Radiometry is that branch of optics concerned with the measurement of the radiant energy or power flowing in beams of optical electromagnetic radiation including, primarily, incoherent ultraviolet, visible, and infrared radiation, as well as longer or shorter wavelengths in circumstances wherein the laws of geometrical optics apply. With the rapidly increasing interest in coherent radiation, resulting from the explosive development of laser technology, there is growing need for more adequate treatment of the problems of measuring radiant power in coherent beams as well, in which its distribution is strongly affected by the phase relations that give rise to interference. Radiometric relations based on the classical geometrical optics of the literature cited here should not be applied blindly to situations involving coherent radiation.[1]

The largest subdivision of radiometry includes photometry and illumination engineering, wherein radiant energy is measured in terms of its effect on the average or "standard" human eye (spectral luminous efficacy of radiant flux $K(\lambda)$, formerly called "luminosity factor"). In optical pyrometry, radiant energy is measured to determine temperatures. Radiometry plays a major role in the radiant-heat-transfer area of mechanical and chemical engineering. Meteorologists and astrophysicists are also interested in radiative heat transfer, but from a somewhat different standpoint. Radiant-heat-transfer problems are increasing in importance and are encountering new conditions in connection with spacecraft temperature control. Ceramic engineers are greatly concerned with radiometric considerations, not only in developing materials for space applications but also in mundane areas such as the cooling of glass sheets during their manufacture. Ophthalmologists and optometrists, as well as optical-instrument designers and manufacturers, are also concerned with radiometric relations and measurements. Radiometry occupies a large place in the growing military applications of electrooptical devices, especially in the infrared. Meteorologists and climatologists, foresters, and other biologists concerned with the effects of radiant energy, particularly solar radiant energy, on plants and animals make extensive use of radiometric relations and measurements. Radiometric instruments are used in medicine, for example, to detect and map anomalous patterns of skin temperature associated with diseased conditions, particularly circulatory difficulties. They are also used in industrial inspection and control, e.g., to detect defective circuits and components and poor layout and design of electronic assemblies, by the infrared radiation resulting from undue heating. This listing is far from exhaustive.

I have collected a working list of over 1000 references, primarily in connection with a continuing effort to improve and expand a preliminary general treatment of radiometric calibration.[2] These references have been gathered partly through subject searches in Science Abstracts, Engineering Index, etc., but mainly on the basis of citations encountered as particular problems have been explored from time to time; these, in turn, have led to others, and so on. I am convinced that a really systematic and exhaustive collection effort would turn up many more pertinent items. For this resource letter, only a few of the most important basic references—those having the widest application—have been selected.

I. GENERAL TREATMENTS

There seems to be no completely general treatment of radiometry, as such. There are good optics texts that cover many fundamentals, but most of them do not devote much attention to radiometric considerations. Then there are treatments of radiometry that manage to achieve enough generality to be useful as basic references, even though they are primarily concerned with certain aspects, such as infrared physics, rather than with radiometry as a whole.

1E. *Measurement of Optical Radiations—The Detection of Electromagnetic Radiation from Ultraviolet to Infrared.* Georg Bauer (The Focal Press, London and New York, 1965). Translation by K. S. Ankersmit of *Strahlungsmessung im optischen Spektralbereich* (Friedr. Vieweg und Sohn Verlag, Braunschweig, 1962). This probably comes as close as any to being a good introductory treatment of radiometry in general. In a good review, E. J. Gilham deplores Bauer's bias toward principles rather than practice in such an introductory volume. However, this is probably unavoidable in any general treatment and I welcome it, particularly since it can easily be supplemented by good accounts of actual measurement practices in reports of specific experiments and studies. It is unfortunate that there are some shortcomings in the translation, but some of the same difficulties of inadequate or ambiguous terminology are also frequently encountered in texts written directly in English, so the reader may as well learn from the outset to cope with them (see discussion of nomenclature, below). There are also citations of sources for more extensive and intensive treatments of particular topics, but many of them are in German. [Reviewed by: E. J. Gilham, Brit. J. Appl. Phys. **16**, 1407 (1965); D. L. MacAdam, J. Opt. Soc. Amer. **55**, 898 (1965)].

2E. *Measurement of Radiant Energy.* W. E. Forsythe, Ed. (McGraw-Hill Book Co., New York, 1937). This, too, is a general treatment of radiometry, as its title indicates. Unfortunately, it is somewhat out of date. However, it is still a good reference on many topics and certainly is an excellent summary as of 1937, as well as being almost the only reference in which all of the topics treated can be found together in a single volume.

3E. *Handbook of Military Infrared Technology.* William L. Wolfe, Ed. (Office of Naval Research, Washington, D. C., 1965, Supt. of Doc., USGPO Washington, D. C. 20402—$3.75), 906 pp. While its emphasis is on the infrared region of the spectrum and on military applications, this reference volume contains much useful information on radiometric fundamentals; also, the coverage is complete enough in many places so that, to some extent, it can serve as a text as well as a reference volume. At the price, it is a real bargain. [Reviewed by: J. N. Howard, Appl. Opt. **6**, 2200 (1967); D. L. MacAdam, J. Opt. Soc. Amer. **57**, 588 (1967).]

4E. *Applied Optics and Optical Engineering. Vol. IV*, R. Kingslake, Ed. (Academic Press Inc., New York, 1967). (Vols. I and II, 1965; Vol. III, 1966; Vol. V is in preparation). Chapter 8, p. 263, in Vol. IV presents a general treatment of radiometry in very limited space. Fortunately, some topics such as instrumentation and atmospheric phenomena are covered in other chapters of the same treatise. The chapter is organized around an examination of reasons why the precision and accuracy achievable in radiometry are so poor, in contrast to those attained in most other types of physical measurements. I have since become increasingly aware of the existence of many more significant publications in addition to those I consulted in writing that chapter. A good example is Gershun [5]. [Reviewed by: S.S. Ballard, Appl. Opt. **7**, 252 (1968); R. A. Hills, Jr., J. Opt. Soc. Amer. **58**, 591 (1968).]

5A. *The Light Field.* A. Gershun. English translation by Parry Moon and Gregory Timoshenko. J. Math. Phys. **18**, 51 (1939). (MIT, Elect. Eng. Dep. Contribution No. 164, 1939). This is a vector treatment of the geometrical relations of radiometry. A study of portions of it reveals it to be elegant and complete. It treats radiometric quantities as field quantities, as I have long felt they should be treated, and clearly states the invariance properties of radiance, pointing out their power and usefulness.[3] Although photometric terminology is used throughout, it is clearly stated at the outset that the geometrical relations apply equally to all radiometry, regardless of the units in which radiant power is measured, so that radiometric quantities may be substituted everywhere for the corresponding photometric quantities. It seems surprising that this publication is not more widely known and recognized.

6A. "Temperature Radiation of Solids." G. A. W. Rutgers, in *Handbuch der Physik,* Vol. **26**, S. Flügge, Ed. (Springer-Verlag, Berlin, 1958), p. 129. As indicated by the title, this treatment does not cover directly certain important phases of radiometry, such as radiation from gases. However, it is an authoritative presentation of much material that is basic to all radiometry.

7E. *Light.* R. W. Ditchburn (Interscience Publishers, John Wiley & Sons, Inc., New York, 1963), 2nd ed. This comprehensive treatise emphasizes physical optics. It includes a good, though brief, discussion of much basic material on radiometry, particularly in Ch. X, "Detection and Measurement of Radiation." [Reviewed by: S. P. Davis, Appl. Opt. **3**, 14 (1964); D. L. MacAdam, J. Opt. Soc. Amer. **55**, 898 (1965).]

8A. *The Theory of Optics.* Paul Drude. Translated from the German by C. Riborg Mann and Robert A. Millikan (1902). (Dover Publications, Inc., New York, 1959). (Preface to German edition is dated January 1900). Although not modern, this classic stands up well. It contains much useful material on basic principles of radiometry, especially in Part III, "Radiation." In particular, Kirchhoff's law relating emissivity and absorptance is correctly stated in terms of the directional quantities, and the implication that follows concerning polarization of oblique emitted rays is clearly pointed out (something that, strangely, has been overlooked in recent texts).[4]

9A. *The Detection and Measurement of Infrared Radiation.* R. A. Smith, F. E. Jones, and R. P. Chasmar. (The Clarendon Press, Oxford, 1968), 2nd ed. Fundamentals are well presented with primary attention to the infrared, especially the properties of detectors for that spectral region. [1st ed. (1957) reviewed by: D. M. Gates, J. Opt. Soc. Amer. **48**, 198 (1958).]

10E. Proceedings IRE, Vol. **47**, No. 9, September 1959—Infrared Issue. This special issue was prepared primarily by workers in military applications of infrared, under the general supervision of Stanley S. Ballard as guest editor, to summarize the growing body of unclassified knowledge in this field. Dr. Ballard has also summarized the evolution of subsequent publications in this field, including a number of excellent book reviews, in his Applied Optics feature "Optical Activities in the Universities," especially in **1**, 585 (1962); **2**, 323 (1963); **3**, 219 (1964); **5**, 1043 (1966); and **5**, 1256 (1966).

11E. "Infrared Target and Background Radiometric Measurements–Concepts, Units and Techniques." G. Kelton, G. F. Levy, E. Bell, L. M. Biberman, G. E. Brown, J. N. Hamilton, R. C.

Jones, D. S. Lowe, R. Paulson, G. J. Zissis, M. R. Nagel, L. Nichols, N. E. Beardsley, E. Wormser, E. M. Sevadjian, and J. A. Sanderson. Infrared Phys. **3**, 139 (1963). Also report of the Working Group on Infrared Backgrounds (WGIRB). Report No. 2389-64-T, IRIA, Inst. of Sci. and Tech., The University of Michigan, Ann Arbor (AD-275810) (Jan. 1962). A tremendous essay at standardization and simplification was worked out very thoroughly by a rather large committee, (WGIRB), in this area of military infrared applications. This is an excellent source of radiometric fundamentals.

12A. *Fundamentals of Infrared Technology*. M. R. Holter, S. Nudelman, G. H. Suits, W. L. Wolfe, and G. J. Zissis. (The Macmillan Co., New York, 1962). This text grew out of the lecture notes for a summer course of the same title at the University of Michigan. The authors are concerned primarily, though not exclusively, with military applications. [Reviewed by: W. G. Langton, Appl. Opt. **2**, 364 (1963).]

13E. *Photometry*. J. W. T. Walsh. (Constable and Company, Ltd., London, 1953), 2nd ed., rev. (Also 3rd ed., 1958; reprinted by Dover Publications, Inc., New York, 1965.) An authoritative classic with a wealth of useful information on basic radiometry as well as on the more specialized considerations of photometry. [Reviewed by: W. E. K. Middleton, Appl. Opt. **5**, 147 (1966).]

14A. *The Scientific Basis of Illuminating Engineering*. Parry Moon. (McGraw–Hill Book Co., New York, 1936). (Dover Publications reprint, with additional conversion tables and bibliography, New York, 1961). This volume seems harder to read than [13], in part, perhaps, because I have had less occasion or opportunity to refer to it. It is frequently cited as a classic.

15A. "Radiant-Heat Transmission." Hoyt C. Hottel. In *Heat Transmission*, W. H. McAdams (McGraw–Hill Book Co., New York, 1954), 3rd ed., Ch. 4. Radiometry is presented here as developed by engineers concerned with radiative heat transfer. While the underlying principles are the same, the approaches and terminology are quite different in many respects from those in the previously cited sources.

16A. "Atmospheric Transmission: Concepts, Symbols, Units and Nomenclature," I. J. Spiro, R. Clark Jones, and D. Q. Wark. Infrared Phys. **5**, 11 (1965). Although the title indicates that this paper is concerned primarily with nomenclature, there is an appendix on radiometry by Jones that outlines fundamentals from a fresh and stimulating point of view (see [25] below) in an attempt to deal more adequately with situations involving propagation through the atmosphere and emission and reflection by natural objects. The paper was written at the instigation of the Specialty Group on Infrared Backgrounds and Atmospheric Physics of the Infrared Information Symposia (IRIS), sponsored by the Office of Naval Research.

17A. *Vision Through the Atmosphere*. W. E. K. Middleton. (Univ. of Toronto Press, Toronto, Canada, 1952). Many workers, even when not directly concerned with atmospheric visibility, have found this a very useful text and reference on radiometric and photometric fundamentals, including nomenclature.

There are three new publications that, unfortunately, I have not had the opportunity to study sufficiently to be able confidently to assess their value in relation to the others listed above. However, from skimming them or from information about them, it appears that they should not be omitted from this list.

18A. *Infrared Radiation: A Handbook for Applications*. M. A. Bramson. (Plenum Press, New York, 1968). The treatment of thermal radiation and associated radiance contrasts seems to be particularly complete, with many useful tables. The implications and interrelationships between spectral distributions in terms of wavelength, wave number, or frequency and in terms of radiant energy or quanta and their graphs or measures on logarithmic or linear scales also appear to be covered quite thoroughly.

19A. *Radiation Heat Transfer*. E. M. Sparrow and R. D. Cess. (Brooks/Cole Publishing Co., Belmont, Calif., Div. of Wadsworth Publ. Co. Inc., 1966). This book might replace [15] as a more up-to-date treatment from the standpoint of heat-transfer engineering. Incidentally, there appears to be a good discussion and a convenient catalogue of angle factors (projected solid angles in steradians divided by π, the projected solid angle of a hemisphere).

20A. *Infrared System Engineering*. Richard D. Hudson, Jr. (John Wiley & Sons, Inc., New York,

1969). Although I have not yet seen this book, I am informed[5] that it is "strictly up-to-date on the physics and technology of the infrared, written from the systems point of view. See especially Ch. 2, Infrared Radiation, and Appendix 2, Symbols and Nomenclature for Radiometry and Photometry."

II. NOMENCLATURE

Nomenclature (concepts, terms, and symbols) is important in three ways. First, well-defined self-consistent nomenclature is essential for clear thinking, for the formulation of problems and propositions about radiometric quantities and their interrelationships, and for their successful manipulation to derive new relationships and to solve problems. Second, a somewhat broader appreciation of the variations and subtleties in the nomenclature in current use is needed for effective communication with contemporaries. Finally, a much more comprehensive grasp of the wide variations that occur in nomenclature, past as well as present, is needed for full access to and use of the large body of heterogeneous literature on radiometry that is only sampled here.

From the present introduction to the diversity in radiometric literature, it is clear that nomenclature differences lie at the core of the problem of achieving maximum availability and use of existing resources in that literature. Even if, by some miracle, complete standardization could eliminate the plague of nomenclature differences overnight, there would still remain the very substantial body of existing literature wherein diversity is an established fact that cannot be ignored if we are to make use of it. However, before considering how to cope with this problem, in the absence of adequate keys and tables of corresponding items in the different nomenclature systems and practices, we note the recent rapid and substantial progress toward standardization. Probably the best example is:

21E. *USA Standard Nomenclature and Definitions for Illuminating Engineering*, RP-16 (USAS Z7.1–1967). Approved August 16, 1967, by USA Standards Institute. Sponsored, published by, and available from the Illuminating Engineering Society, 345 E. 47th St., New York, N. Y. 10017. This monumental document is clear, complete, and well indexed. As indicated in its foreword, it is the culmination of an extensive effort, including wide coordination on an international scale.[6]

Adoption of the radiometric nomenclature of [21] is rapidly gaining momentum, and it clearly seems destined for wide acceptance. In particular, I understand that the editors of the Journal of the Optical Society of America and Applied Optics, and of the forthcoming OSA Handbook of Optics as well, have indicated that they will adopt the nomenclature of [21], strongly recommending its use in contributions to their publications. However, I hope that they continue to permit variations and departures when an author has strong reasons for them, lest the standards become a straitjacket that stifles desirable innovation and progress. Also, in view of this accelerating crystallization of a long-needed standard nomenclature, it is important to recognize aspects that make some of us accept it with less than complete enthusiasm, even while we recognize that the advantages far outweigh our objections.

Although the definitions and interrelationships are clearly stated in [21], the adoption of symbols that come from photometry, with subscripts added where needed to distinguish the radiometric from the corresponding photometric quantities, may unintentionally encourage illogically anthropomorphic tendencies to treat the standard human eye as a primary detector. It is important to point this danger out, particularly when introducing the nomenclature to students. This is not just a quibble over prestige between radiometry and its overshadowing branches of photometry and illumination engineering: important practical considerations are involved, as has been eloquently pointed out by Biberman [22]:

22E. "Apples, Oranges and Unlumens." Lucien M. Biberman. Appl. Opt. **6**, 1127 (1967). ". . .Luminosity is related to the human eye, not to an S-20 cathode or photographic emulsion. The absurdity of applying photometric units to non-eye-related functions is illustrated, and a plea made for proper use of radiometric terminology." [From author's abstract.] This letter to the editor touched off a series of letters in which the topic is further explored: F. H. Barr and E. H. Eberhardt, "On the Elimination of the Lumen from the Responsivity Calibration of Photodetectors," Appl. Opt. **6**, 1575 (1967); H. K.

Hammond III, "Phototube Response Evaluation," Appl. Opt. 7, 985 (1967); F. E. Nicodemus, "Radiometry with Spectrally Selective Sensors," Appl. Opt. 7, 1649 (1968).

To summarize briefly, radiometry is, logically, the broad field covering all forms of radiant-power measurements, including those with selective instruments having responsivities that vary as functions of one or more of the radiation parameters: wavelength or frequency, position, direction, fluctuation or modulation frequency, and polarization. The output of a radiometer is then just the weighted integral of the distribution function, describing the incident radiation in terms of these parameters, weighted by the responsivity function of the instrument. Photometric units are a particular case, albeit a very important one, of such a weighted response, wherein the weighting function is the luminosity function representing the spectral responsivity of the standard photopic human eye. But any intercomparison of photometric results with those of other selective sensors (e.g., photocells or photographic films) requires computations that are equivalent to transforming all results to absolute radiometric units.

As suggested in the comments on [1], the reader of the radiometric literature is constantly plagued by inadequate and ambiguous nomenclature. Until there is time for standardization to take full effect, the problem remains; I have found two techniques effective for coping with it: to prepare a glossary or translation table as I read, and to make frequent use of dimensional analysis. When I want to be meticulous, I set down in a list each of the author's radiometric terms and symbols, as they are introduced, together with their definitions, if given. The corresponding terms or symbols in my own familiar nomenclature are listed as soon as I am able to identify them, rechecking as I go along to see if the author's use of them is consistent with my identification. In addition, by applying dimensional analysis to each relationship and equation, the consistency can be even more thoroughly checked through particular attention to the units given for each quantity. Not infrequently, inconsistencies appear, possibly even because the author is in error; then it becomes a problem to discover where the error occurred and to determine what is really meant by the statements made. Admittedly this takes time, but it is essential for understanding. Often, however, such elaborate precautions are not needed, especially after one has formed the habit of making these critical examinations and can do much of it mentally as he reads. But the confusion resulting from failure to understand and interpret a particular term or symbol correctly can frequently cost far more in lost time and effort than is required for this procedure; a few such instances will usually convince one that the time spent in systematically translating any difficult analysis or derivation into more familiar terms and symbols will prove to be a time-saving rather than a time-consuming exercise.

The general references already cited above are, of course, also sources for radiometric nomenclature. The possible shortcomings of Bauer [1], arising out of translation, have been noted. There is a good summary of much of the radiometric nomenclature in Wolfe [3], particularly in Ch. 2, Radiation Theory. In [4], I made some mention of variations in nomenclature, but, for the most part, I concentrated on trying to present a clear, consistent scheme of nomenclature based on my own preferences at that time (now I would follow [21]). Gershun [5], Walsh [13], Moon [14], and Middleton [17] are good sources for the nomenclature used in photometry and illumination engineering, and Moon [14] also tabulates, in the latest Dover edition, the "improved system" of quite different nomenclature, which is employed primarily by Domina Eberle Spencer and himself in numerous publications on illumination engineering (see [30], below). Hottel [15] and Sparrow and Cess [19], as indicated, employ the nomenclature of radiative-heat-transfer engineering. Spiro, Jones, and Wark [16] are primarily concerned with standardization of nomenclature for situations involving atmospheric propagation.

23E. *The Science of Color*. Optical Society of America, Committee on Colorimetry. (Thomas Y. Crowell Co., New York, 1953, reprinted 1966 by Optical Society of America, available from address given in preface of this Resource Letter). The Glossary-Index of this excellent volume is one of the best available sources for authoritative information about optical (including radiometric) nomenclature, particularly the nomenclature used by a large group in the Optical Society of America (OSA). A greatly expanded glossary of this type, with references to all publications containing significant material on radiometric nomenclature, preferably supplemented by extensive tables of equivalents, would be tremendously valuable as a dictionary to make much more of the existing radiometric literature available and useful to a much larger community of scientists and engineers.

24E. "Radiometric Quantities, Symbols and Units." E. E. Bell. Proc. IRE **47,** 1432 (1959). A presentation of essentially the nomenclature recommended by Kelton *et al.* (the WGIRB) [11] that has been rather widely adopted in the community of scientists and engineers working on military infrared applications in this country.

25E. "Terminology in Photometry and Radiometry." R. Clark Jones. J. Opt. Soc. Amer. **53,** 1314 (1963). This is a proposal for an ingenious system of concepts and terminology that clearly recognizes the underlying geometrical relations common to radiometry and photometry and to the propagation of any quantity that obeys the laws of geometrical optics—one that is propagated in straight lines in a homogeneous isotropic medium, at a constant speed characteristic of the medium and without interference. Jones has coined the term *phluometry* for this underlying system of common geometrical relationships. His ideas, developed further in the appendix to [16], are important even if his proposed nomenclature is never widely used.

There follow some sources for the nomenclature currently in wide use in various areas, some for that used in earlier times (which will still be encountered when cited references are consulted) and some that intercompare the nomenclature used in different areas.

26E. "How to Understand and Use Photometric Quantities." Kodak Tech Bits No. 1, pp. 2–5, 15. (Eastman Kodak Co., Rochester, New York, 1965). This is a good, simple, practical summary of the most generally used photometric nomenclature, with some illustrative applications.

27A. "Bridging the Language Gap in Radiation Heat Transfer." Thaddeus C. Grimm. Chem. Eng. **72,** 117 (1965). A direct intercomparison is made between the nomenclature used in photometry and illumination engineering and that used in heat-transfer engineering.

28E. Journal of Heat Transfer (ASME Trans., Ser. C). This journal follows the commendable practice of tabulating the nomenclature used in each paper on the first page of that paper. Unfortunately, the definitions of the symbols and terms are not always complete or rigorous, thus leaving room for ambiguity and misunderstanding, particularly since the units or physical dimensions for each quantity are not always given. Nevertheless, a quick scan through these tabulations in a few issues of the journal can give a very good idea of the nomenclature generally used by radiative-heat-transfer engineers.

29A. "The Units and Nomenclature of Radiation and Illumination." H. E. Ives. Astrophys. J. **45,** 39 (1917). This is primarily of historical interest. It is perhaps encouraging to note that, confused as the present situation seems, it has been even more confused in times past.

30A. "Study of Photometric Nomenclature." Parry Moon and Domina Eberle Spencer. J. Opt. Soc. Amer. **36,** 666 (1946). The proposals and the arguments in support of them, as presented here, have not gained wide acceptance. However, much interesting historical and factual material is also presented.

31A. "Survey of Radiometric Quantities and Units." W. Viezee. The RAND Corp., Santa Monica, California, Res. Mem. No. RM-2492 (AD-241,636) (July 12, 1960). Even though this report is not available in a recognized journal, it is cited here because, for those who wish to obtain a copy,[7] it is a very good discussion of a wider scope than most. The radiative-heat-transfer nomenclature of the meteorologist or astrophysicist, rather than that of the engineer, is related to the historical development of photometric nomenclature.

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1 A. Walther, "Radiometry and Coherence," J. Opt. Soc. Amer. **58,** 1256 (1968).

2 "Methods of Radiometric Calibration," F. E. Nicodemus and G. J. Zissis. (The University of Michigan, Contract No. SD-91 with the Advanced Research Projects Agency, Report 4613-20-R, October 1962) (Defense Documentation Center No. AD-289, 375.)

3 This is my message in "Radiance." F. E. Nicodemus, Amer. J. Phys. **31,** 368 (1963).

4 O. Sandus, "A Review of Emission Polarization," Appl. Opt. **4,** 1634 (1965).

5 Personal communication from S. S. Ballard, editor of the series in which this book appears. *Note Added in Proof:* Having now seen this book, I recommend it enthusiastically. Unfortunately, it uses the nomenclature of [11] rather than that of [21]. However, it is particularly well organized and it includes extensive and well-annotated bibliographic material. Reviewed by: D. J. Lovell, Appl. Opt. **8,** 1638 (1969); W. L. Wolfe, J. Opt. Soc. Amer. **10,** 1389 (1969); W. F. Jaskowsky, Amer. Scientist **57,** No. 4 373A (1969).

6 See also D. B. Judd, "Symbols, Nomenclature and Units," J. Opt. Soc. Amer. **52,** 954 (1962), and several related articles in the June 1960 issue (Vol. 15, No. 6) of Phys. Today. See also OSA Nomenclature Committee Rept., J. Opt. Soc. Amer. **57,** 854 (1967), and review of [21] in J. Opt. Soc. Amer. **58,** 864 (1968).

7 Available directly from the RAND Corp., 1700 Main Street, Santa Monica, California 90406 (or, to qualified requesters, from the Defense Documentation Center—DDC).

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Anniversaries in 1970 of Interest to Physicists

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During the year 1970 there are major anniversaries of the birth or death of seven men whose accomplishments and influence have been of importance to the development of physics. They are: Alexandre Edmond Becquerel, Henry Andrews Bumstead, Heinrich Gustav Magnus, Jean Baptiste Perrin, William John Macquorn Rankine, Simon Stevin, and John Tyndall. Brief accounts of their careers are given here.

The group presented here[1] consists of a Nobel laureate, the father of a Nobel laureate, two distinguished teachers, "The Father of Modern Statics," a great applied physicist, and one of the great popularizers of physics.

As in the past,[2] my information sources are fallible and sometimes conflicting, so I will be grateful if errors are brought to my attention.

The sequence of anniversary dates during 1970 is (b, birth; d, death): 12 March, Bumstead, 100 b; 24 March, Becquerel, 150 b; 4 April, Magnus, 100 d; 5 July, Rankine, 150 b; 2 August, Tyndall, 150 b; and 30 September, Perrin, 100 b. The sketches follow in chronological order with respect to date of birth.

Stevin, Simon, 1548–1620, Belgian (Fig. 1). According to Sarton,[3] Stevin was "undoubtedly the most original man of science in the second half of the sixteenth century," and the most notable contributor to mechanics between Archimedes and the 15-years-younger Galileo. He was the first to continue Archimedes' studies in mechanics and has been called the Father of Modern Statics. He may have been the first to use vectors to represent forces, and his famous "thought experiment"—a technique he introduced—involving a chain hung over an inclined plane, led him in 1586 to the idea of forming and combining force components. He distinguished among the three classes of equilibrium and his use of virtual displacements led to the concept of work. In about 1586 he and a friend investigated the fall of balls of unequal weights, prior to Galileo. He also contributed usefully to hydrostatics, discovering the "hydrostatic paradox" before Pascal, and working with what Bouguer later named the "metacenter," a factor in boat stability. He found that hydrostatic pressure depended upon density and vertical height only, and was able to calculate forces due to pressure. In 1599 he published for 43