Comments and Communications

Night Temperatures and the Moon

HENSTOCK (SCIENCE, 116, 257 [1952]) has reported on the fall of the minimum temperature at or near the full moon. The writer made a similar study while he was a student at Colgate University in 1947. A remark by John Littlefield, treasurer of the university, to the effect that a full moon in winter was followed by a cold snap, led to an analysis of the lunar month on the basis of the variations in mean temperature.

Mean daily temperatures for the Syracuse, N. Y., area were obtained from Weather Bureau *Monthly Climatological Summaries* for the years 1931 through 1946. After subtracting the daily normal temperature (*Annual Meteorological Summary, Syracuse, N. Y.*, U. S. Dept. Commerce, Weather Bureau [1945]) from each of the mean daily temperatures, the variations were recorded according to the day of the lunar month. The data were then averaged (Table 1 [1]) and graphed (Fig. 1 *A*). Aside from the rise in mean temperatures just before the first quarter and just following the full moon, the variations were slight and seemed of little significance. It was then decided to analyze the data on a seasonal basis. Accordingly, the data were divided into a summer period (Apr. 20–Aug. 20) and a winter period (Oct. 20–Feb. 20). The data for the 30 days before and after the equinoxes were omitted.

TABLE 1

AVERAGE VARIATIONS OF MEAN TEMPERATURE MINUS DAILY NORMAL TEMPERATURES FOR EACH DAY OF THE LUNAR MONTH, SYRACUSE, N. Y.

Day of lunar month	1. All lunar months, Jan. 1931–Dec. 1946 (195 lunar months)	2. Summer period, Apr. 20–Aug. 20, 1931, to 1946 (63 lunar months)	3. Winter period, Oct. 20–Feb. 20, 1931, to 1946 (64 lunar months)
(New moon)	—	—	—
1	+ 3.2*	+ 2.7*	+ 2.5*
2	3.4	2.3	2.7
3	3.1	2.5	2.8
4	2.4	2.4	2.3
5	3.2	3.2	3.2
6	3.8	2.8	4.4
7 (First	3.1	3.4	3.5
8 quarter)	1.8	2.4	1.7
9	2.5	3.1	2.9
10	2.4	2.8	2.4
11	2.3	3.4	1.6
12	2.6	3.8	2.1
13	2.3	2.9	2.8
14	2.1	3.0	2.3
15 (Full moon)	2.6	3.7	2.1
16	3.9	4.0	3.3
17	3.0	3.0	3.3
18	3.3	4.0	2.3
19	3.0	4.3	1.7
20	3.5	4.6	1.1
21	3.1	4.7	1.3
22 (Last	3.1	4.4	0.8
23 quarter)	3.2	3.9	1.3
24	3.0	3.7	1.5
25	2.3	3.4	1.3
26	2.4	2.5	1.6
27	2.3	2.3	2.6
28	2.9	1.2	0.7
29	2.4	2.3	2.7
30 (New moon)	3.2	3.0	3.7

* All variations are positive.

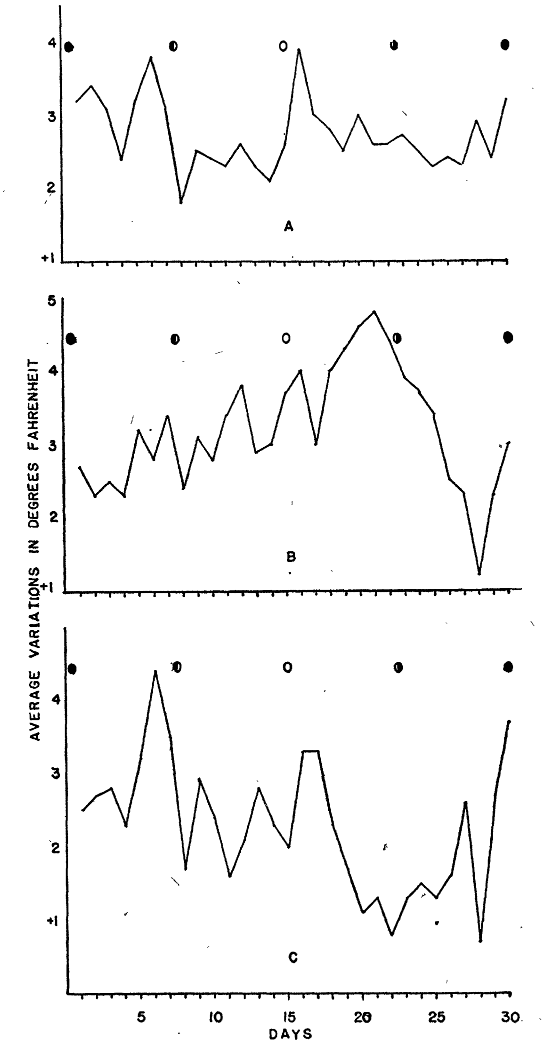

FIG. 1. Variations in mean daily temperature, arranged according to the day of the lunar month. Data from Jan. 1931, through Dec. 1946, Syracuse, N. Y. *A*, all lunar months; *B*, summer period, Apr. 20–Aug. 20; and *C*, winter period, Oct. 20–Feb. 20.

The results were striking. During the summer period (Fig. 1 B) there is a gradual increase in temperature from just prior to the new moon until a week after the full moon, followed by a relatively rapid fall of 4° within the next week. The lowest point is reached two days prior to the new moon. The situation during the winter period is not quite as clear-cut (Fig. 1 C). From just prior to the new moon until the first quarter, an irregular but marked rise in temperature takes place, over a range of approximately 4°. Between the first quarter and the full moon, a slump occurs, with a fairly distinctive high ending it immediately following the full moon. This slump is a crude inverse of the rise during the same interval of the summer period. Another marked slump follows, between the full moon high and the new moon, reaching its lowest point two days prior to the new moon. This slump is essentially the inverse of the rise that occurs during the summer period following the full moon.

The following features seem to be characteristic of temperature change during the lunar month: (1) an increase one or two days prior to the first quarter, (2) a marked general slump following the first quarter, (3) a slump at or just prior to the full moon, (4) a marked increase just following the full moon, followed in turn again by (5) a slump, and (6) the lowest point (during the summer and winter periods only) occurring just before the new moon. Since each of these rises or falls seems to occur without regard to time of year, they are probably influenced principally by the moon, but the summer rise and winter fall, particularly during the period of the last quarter, are influenced in part by the sun. The author has no desire to hazard a guess as to how these temperature changes are accomplished.

Although it is difficult to conceive of a person's senses being aware of these average changes, Mr. Littlefield's remark appears justified, in that a colder period seems consistently to have followed a full moon in winter. Likewise the adage that grain should be sown in the light of a full moon finds justification in the week or so of warmer weather that commonly follows a full moon in the summer period. As crude as the statistical techniques were, the results indicate that further research with defined methods would be of great interest.

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REFERRING to the paper by Herbert Henstock on "Minimum Night Temperatures at or Near Full Moon," I took an interest in this question over 20 years ago, when a friend remarked that the coldest weather of the month always came at full moon. At that time I was unable to corroborate this and concluded that it was just a superstition. This matter would be of considerable practical importance here, as we are subject to spring frosts that sometimes cause severe losses to the fruit crop.

Mr. Henstock's paper prompted me to re-examine the question, and I have taken the U. S. Weather Bureau data for Yakima, Wash., for the period January 1949 to August 1952, and have plotted the daily minimum temperatures. This period included 45 full moons. I have also plotted the daily minimum temperatures for March, April, and May for the past 15 years, since this is the period when damaging frosts occur. This also included 45 full moons.

In each case, counting in the occasions when two equal falls occurred, one at full moon and one at some other time, the greatest fall came at full moon on only 20 occasions out of 45. Although this is more than would be expected, since the 6-day period around full moon is only about one fifth of the total time, it is far from being the rule. Of the 14 occasions of greatest fall at full moon during the past 3½ years, 3 came in 1949, 8 in 1950, 3 in 1951, and none so far in 1952. Thus the distribution is erratic.

Weather Bureau records show we had damaging frosts in 1943, 1946, 1948, 1949 (three times), 1950, 1951, and 1952 (three times). Of these 11 occasions, the temperature fall causing them has occurred near full moon only 5 times. Evidently Henstock's theory does not apply very well here, and we could not count on it for predicting damaging frosts. Fortunately, we now have a very efficient frost-warning service provided by the Weather Bureau, so that such predictions are unnecessary.

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HENSTOCK has presented summaries of minimum night temperature falls at or near full moon for many places in the world and for three different years. The daily minimum temperatures allegedly show a regular fall at or near the date of full moon at each lunation. The temperature fall may be abrupt or gradual, and the downward trend does not always terminate on the date of full moon but sometimes within two or three days before or after.

Temperature records for 12 stations allegedly show the fall of minimum temperatures at or near full moon to be greater than the average yearly normal temperature fall at the same stations. If the average yearly normal temperature fall was determined from all the downward temperature trends during the year and compared with selected large ones that occurred near full moon, it is easy to see how consistent differences were obtained.

If the greatest minimum temperature fall is associated with full moon, then at other times during the lunar cycle the minimum temperature fall must be less. This hypothesis lends itself to statistical treatment of the data by several methods, one of which employs the greatest minimum temperature fall during comparable 7-day intervals. Thus, if the date of full moon is used as the midpoint of a 7-day interval, the interval would extend three days before and three days after full moon. According to Henstock, this interval should encompass the termination, if not all, of the greatest minimum temperature falls at or near full moon. Similar intervals before and after the full moon period would provide suitable comparisons for statistical treatment of the data.

To test Henstock's hypothesis a 10-year temperature record was obtained from files in the University of California Experiment Station at Riverside. The dates of full moon from January 1942 through December 1951 were obtained from the *World Almanac.* Columns of minimum temperatures for the 10-year period were marked off in 7-day intervals so that each lunar cycle was divided into four 7-day intervals, with the third one centering on the date of full moon. The intervals would roughly coincide with the phases new moon, first quarter, full moon, and last quarter. One or two extra days each lunar month were not included in the intervals as marked on the tabulations of temperatures, but, as will become apparent, the temperatures on these extra days were considered in determining temperature fall.

The greatest fall in minimum temperature for the 7-day intervals during each year of the 10-year period was determined as follows: The greatest downward trend in minimum temperature for two or more consecutive days during each interval was tabulated. When the downward trend began in the previous interval or during the extra days mentioned above, the total downward trend was recorded for the interval in which the trend ended. Thus, the downward trend associated with full moon could start before the full moon interval but was required to end within it. Two or more consecutive days with the same minimum temperature were not considered to terminate a downward trend in minimum temperature unless further fall did not occur. The same rules were followed in determining the fall in minimum temperature for each of the intervals, in order to eliminate any bias.

The greatest fall in minimum temperature for two weeks before, one week before, the week of, and the week after full moon were thus determined for each of the 12 or 13 full moons per year for the 10-year period (Table 1).

TABLE 1

Intervals in relation to full moon	Greatest fall in minimum temperature (°F) (Means of 124 lunar cycles)
2 weeks before full moon	10.40
1 week before full moon	9.31
Week of full moon	9.86
1 week after full moon	10.11

F-value = 1.03; F-value required for significance at 5% = 2.62.

An analysis of variance showed no significant difference in minimum temperature fall between the full moon interval and the other intervals; hence the data do not support the Henstock hypothesis that minimum temperature fall is the greatest at or near full moon.

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HENSTOCK'S paper made no comparison of minimum night temperature falls at or near the full moon with falls at other times of the synodic period. It gave results of comparisons between the minimum temperature falls near the full moon and the average yearly falls for several stations. Such a comparison is not valid, since the term at or near full moon permits the analyst to include in the data minimum temperature falls that occur at varying times from the full moon phase. In other words, the analyst may continue looking for a fall in minimum temperature until one occurs, even though it occurs far from the full moon phase.

To determine if a greater number of minimum temperature falls occurred before, on, or after the full moon, records at three stations—Ottawa, Ont., Regina, Sask., and Edmonton, Alta.—for the years 1950 and 1951 were analyzed by recording the incidence of a fall or rise in minimum temperatures for 13 days before, on, and 13 days after, the full moon phase. The trends in the data were scored on the day the fall or rise started. Ties were not included in the analysis. An example of the tables obtained is shown in Table 1.

Data for winter, spring, summer, and autumn were separately analyzed for both years and all locations,

TABLE 2

χ^2 FOR RISES AND FALLS OF MINIMUM NIGHT TEMPERATURES 1950, 1951, AND THEIR ASSOCIATED PROBABILITIES FOR 26 DEGREES OF FREEDOM, BY SEASONS, FOR REGINA, EDMONTON, AND OTTAWA

	χ^2	Probability
Winter	15.42	$.90 < P < .95$
Spring	17.27	$.90 < P < .95$
Summer	18.09	$.80 < P < .90$
Autumn	36.50	$.05 < P < .10$

TABLE 1

FREQUENCY OF FALLS AND RISES OF MINIMUM TEMPERATURE DURING LUNAR MONTH
Edmonton 1950, 1951

Day after full moon	−13,	−12,	......	−4,	−3,	−2,	−1,	0,	1,	2,	3,	4,	......	12,	13
No. of falls	11,	13,	......	12,	7,	14,	13,	15,	12,	14,	15,	13,	......	13,	10
No. of rises	12,	11,	......	12,	18,	11,	12,	9,	11,	11,	10,	12,	......	12,	15

TABLE 3

χ^2 FOR RISES AND FALLS OF MINIMUM NIGHT TEMPERATURES 1950, 1951, AND THEIR ASSOCIATED PROBABILITIES FOR 26 DEGREES OF FREEDOM, BY LOCATIONS, FOR ALL SEASONS

	χ^2	Probability
Regina	27.37	$.30 < P < .50$
Edmonton	16.90	$.90 < P < .95$
Ottawa	31.31	$.20 < P < .30$

first by the χ^2 test to determine if minimum temperature falls occurred more often on one day than on another. The results are shown in Table 2. For each of the seasons, the χ^2 test in Table 2 gave no evidence of minimum temperature falls occurring more often on one day than on another.

The data were separately analyzed for both years and seasons by means of the χ^2 test to see if minimum temperature falls occurred more often on one day than on another during the lunar month. The results are shown in Table 3.

Since the χ^2 tests are based on data that record only the incidence of a fall or rise and not the magnitude, the minimum temperature falls within 48 hr of the full moon were compared with minimum temperature falls within 48 hr of the new, last, and first quarter phases of the moon. Records at Regina, Edmonton, and Ottawa for 1950 and 1951 were analyzed to determine if minimum night temperature falls within 48 hr of the full moon differed significantly from those at other times of the synodic period.

An analysis was made of the greatest consecutive fall of minimum temperatures within 48 hr of the phases of the moon for twelve synodic periods in 1950 and 1951 for Regina, Edmonton, and Ottawa. The data were obtained separately by stations and years by the analysis of variance to determine if any significant differences would appear between average minimum temperature falls for the phases of the moon. It will be noticed that in Table 4 only two of the six columns show a greater average fall at the full moon than at the other phases. In order to determine if any of these differences were statistically significant the data on which the above averages were based were analyzed by the analysis of variance.

From Table 5 it is apparent that in certain localities minimum temperature falls varied significantly from one part of the year to another. In only one instance did minimum temperature falls differ significantly between the phases (Regina, 1950), and in this instance the minimum temperature fall within 48 hr of the full moon was not as much as that for the other phases of the moon.

TABLE 4

AVERAGE GREATEST CONSECUTIVE FALL OF MINIMUM TEMPERATURES (°F) WITHIN 48 HR OF THE MOON'S QUARTERS, BY STATIONS AND YEARS

	Ottawa		Regina		Edmonton	
	1950	1951	1950	1951	1950	1951
Full moon	6.67	13.92	8.50	12.83	8.83	11.17
Last quarter	9.25	9.92	10.00	13.00	7.25	10.42
New moon	8.00	11.75	14.08	10.92	9.17	10.25
First quarter	9.58	9.17	15.17	12.50	8.67	9.33

TABLE 5

AN ANALYSIS OF VARIANCE OF GREATEST CONSECUTIVE FALL OF MINIMUM TEMPERATURES WITHIN 48 HR OF THE MOON'S PHASES, BY STATIONS AND YEARS

Source of variation	° F	Mean square: Ottawa		Regina		Edmonton	
		1950	1951	1950	1951	1950	1951
Between phases	3	21.14	54.85	122.41	10.41	8.58	6.81
Between periods	11	74.71	137.55	99.92	58.11	15.16	125.63
Error	33	33.70	32.45	38.44	46.66	24.65	46.47

On the basis of the data analyzed here there is no indication of any tendency for the greatest consecutive fall of minimum temperatures within 48 hr of the full moon to be significantly greater than falls for any other phase of the moon.

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IN the article by Herbert Henstock there is a lack of definition of terms. The author speaks of a temperature drop at or near a full moon. Now, in the higher latitudes, there are periods of alternately rising and falling temperatures. Near every full moon there are, then, usually two periods of falling temperature. For instance, the minimum temperatures at Victoria during Apr. 1–7, 1947, inclusive, were 41°, 36°, 38°, 37°, 41°, 40°, 43°. (All Canadian temperatures are taken from *Monthly Record of Meteorological Observations in Canada and Newfoundland,* Department of Transport, Meteorological Division, Toronto.) Why

TABLE 1

	Av temp fall near full moon (Longley)	Av temp fall near full moon (Henstock)	Av normal Temp fall (Henstock)
Victoria	4.4	5.0	4.7
Old Glory	11.8	11.8	10.3
Aklavik	9.9	15.7	9.5
Banff	18.2	19.7	14.6

did the author, with the full moon on Apr. 5, select the drop of 5° between Apr. 1 and Apr. 2, rather than the drop of 1° between Apr. 3 and Apr. 4, or the drop between Apr. 5 and Apr. 6? The minimum temperatures at Banff Jan. 1–9 were, respectively, −19°, −13°, −3°, 11°, −4°, 3°, 13°, 12°, 19°, and the full moon was on Jan. 8. The author picks the drop between 11° and −4°, rather than the one between 13° and 12°. At Aklavik, the minimum temperatures from Feb. 27 to Mar. 5 were −12°, −6°, −24°, −20°, −40°, −40°, −28°. The author refers to a drop of 34° between Feb. 28 and Mar. 3, ignoring the rise between Mar. 1 and 2. With no apparent consistent practice in selecting periods of falling temperature, it is difficult to assure oneself of the validity of Henstock's results.

One could, with reason, define the fall near or at the full moon as follows: If the temperature on the day of the full moon is associated with a period of falling temperatures, in the middle or at either end, that period is to be selected; if the day is found within a period of rising temperatures, the last fall preceding the full moon is to be selected. Using that definition, the average fall was computed for the 13 full moons of 1947. The values are given in Table 1. Also included are the values obtained by Henstock, and his "average yearly normal temperature falls." The latter he does not define clearly, nor does he show the source of his data.

The new set of figures still suggests that the fall of temperature near a full moon is greater than normal, but the evidence is not so overwhelming.

The question could be handled in another manner. There were available average daily changes in minimum temperature at a number of Canadian stations (See Longley, R. W. *The Daily Variation in Temperature,* Technical Circ. No. 81, Meteorological Division, Department of Transport, Toronto [Feb. 1951]). The drops in temperature during the periods of falling temperature near the full moon at some of these stations were compared with the average daily change for part of the year 1947. Out of 165 cases noted, the drop in temperature per day near the full moon was less than the average daily change in temperature in 84 cases, and greater in 81 cases. This does not appear to bear out the hypothesis that the drops in temperature near the full moon are extreme.

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HENSTOCK has reported that the minimum temperatures recorded at several widely scattered stations seem to be related to the phase of the moon. His findings are in sharp disagreement with accepted meteorological knowledge; hence careful analysis of his paper seems to be imperative.

Unfortunately the data and methods employed by Henstock appear to invalidate his findings from the start. The acceptance of his results even as a working hypothesis for further research is not warranted. His data, at most 5 years at one station and single years at the others, are absolutely insufficient in any attempt to evaluate such effects as lunar influences. It should be pointed out that, for example, the establishment of the magnitude of the lunar tide in the atmospheric pressure—which can be shown to exist theoretically—necessitated the use of about 350,000 observations even in tropical latitudes, where the other random effects upon the pressure are small! When dealing with minimum temperatures we must contend with large random effects introduced by air mass changes, variations of insolation, and other factors, which result in a large standard deviation of such temperature values. From the 78-year record of minimum temperature at Boston, Mass., the standard deviation was computed for January to be 10.2° F; and the order of magnitude of this standard deviation is about representative for all stations in temperate latitudes.

From such figures it can be deduced that interdiurnal changes of 10 or more °F are by no means rare occurrences. To obtain significant results for changes of this same order of magnitude, at least several decades of records must be employed. Utilizing 20 years of data from the Boston record, no relationship of minimum temperatures to moon phases could be found. Any attempt to gain more confidence in the results by using more stations is doomed to failure, because the same arguments are valid for other stations also.

Even if the results could be assumed to be statistically significant, they do not necessarily imply any relation to moon phases. Several other explanations are possible. We can compute theoretically the possible stable, free oscillations of the atmosphere. One such wave has a period of about 30 days, and in several papers the actual existence of this wave in meteorological phenomena and its long persistence (of the order of a year or more) have been proved. Such waves in the general circulation of the atmosphere can also be reflected in single elements as temperature, etc. Thus it seems quite possible that it is not the revolution of the moon (the synodic month has a length of approximately 29½ days) that is responsible for the recurrence of low temperatures in intervals of about 29–30 days, but that this is actually a reflection of the free oscillation inherent in our atmosphere in the temperature records of single stations.

Another possible explanation may lie in the often found quasi-persistent recurrence of weather patterns with periods of 7–8 days, and we must take into account possible solar influences geared to the solar rotation with a periodicity of about 27–28 days.

This list of points is by no means complete, but it is sufficient to show the difficulties encountered if the attempt is made to investigate lunar influences upon the weather. Very elaborate statistical procedures must be employed before even preliminary results of sufficient significance can be obtained. For this reason the results and implications of Mr. Henstock's paper are not acceptable. In general, meteorologists still agree that lunar influences upon meteorological elements other than the tidal waves—which are extremely small—have not been adequately demonstrated. Many papers have been published alleging to show such influences, but up to now none has held up under a careful and unbiased scrutiny.

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Book Reviews

The Genetics of the Dog. Marca Burns. Farnham Royal, Bucks, Eng.: Commonwealth Agricultural Bureaux, 1952. 122 pp. and plates. 12s 6d.

Marca Burns is a geneticist as well as a dog breeder, and this little book amply proves the connection. It contains a digest of the world's technical studies of dog genetics, yet is written for the layman with a background of college biology.

Chapters on Mendelian theory, reproduction, conformation, physiological peculiarities, abnormalities and disease, behavior and mental attributes, coat, skin, and color, together with three helpful chapters on breeding systems and the use of genetic formula make it a helpful, useful book to every scientist interested in canine genetics and every layman interested in dog breeding.

The book contains many interesting halftones and line drawings, a glossary, and a 240-item bibliography.

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Investment Castings for Engineers. Rawson L. Wood and Davidlee Von Ludwig. New York: Reinhold Pub., 1952. 477 pp. Illus. $10.00.

The purpose of this text is to acquaint design engineers with the investment process, to help him obtain maximum efficiency and economy from his design and specifications. When selecting a process by which an engineering part is to be produced, the designer weighs all the factors affecting function and cost. In order to do this most effectively he should have more than a general knowledge of all the prospective processes. Also, because of lack of knowledge of a process, a designer may avoid it and consequently not obtain the best results from his design.

After determining the process to be used, an efficient design engineer must have an intimate knowledge of the process so that the part may be designed for most economical production. The text therefore describes the various investment processes in detail. It points out how the various steps in the production of the casting are related to design. For example, in discussing the factors influencing the positioning of the gate, the designer finds that he cannot expect to obtain tolerances less than 0.010 inch near the gate area. In the discussion on "Factors Affecting Die Life," he points out that thin design sections necessitate the use of hardened steel dies in the production of wax patterns, because of higher temperatures needed to produce such sections.

After a brief history of investment casting, the text continues with the production of the master pattern, describing various types of dies obtained from it. This is followed by a very thorough discussion of types of patterns in use. One chapter deals with the "Frozen Mercury Disposable Pattern," a development not too familiar to the average engineer. Information on investment materials and techniques used in producing molds follows, and after a brief description of the melting techniques, the text deals quite thoroughly with ferrous and nonferrous metals used in investment casting. This is followed by information on cleaning, inspecting, and finishing of the castings. The next 90 pages deal with design of castings for the investment process. The last two chapters treat the metallurgical effect of the process on metals, and machinability tests on stainless steels.

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Scientific Book Register

Thermal Diffusion in Gases. K. E. Grew and T. L. Ibbs. New York: Cambridge Univ. Press, 1952. 143 pp. Illus. $4.50.

The Philosophy of Science: An Introduction. Stephen Toulmin. London: Hutchinson's Univ. Library; New York: Longmans, Green, 1953. 176 pp. Illus. $2.25; text ed. $1.80.

Scientific Terminology. (Medical, biological, and general.) John N. Hough. New York: Rinehart, 1953. 231 pp. $3.50.

The Microbiological Assay of the Vitamin B-Complex and Amino Acids. E. C. Barton-Wright. New York–London: Pitman, 1952. 179 pp. Illus. $4.00.