The COLORADO Engineer

May 15, 1961

The COLORADO Engineer

UNIVERSITY OF COLORADO BOULDER, COLORADO

VOLUME 57 NO. 4

Member of Engineering College Magazines Associated, Charles Wales, Chairman, Wayne State University, Detroit 2, Mich.

Circulation: 2200. Published four times a year, on the fifteenth of November, January, March, and May by the students, faculty, and alumni of the College of Engineering.

Publisher's representative— Littell-Murray-Barnhill, Inc., 369 Lexington Avenue, New York 17, N. Y., and 737 North Michigan Avenue, Chicago 11, Illinois.

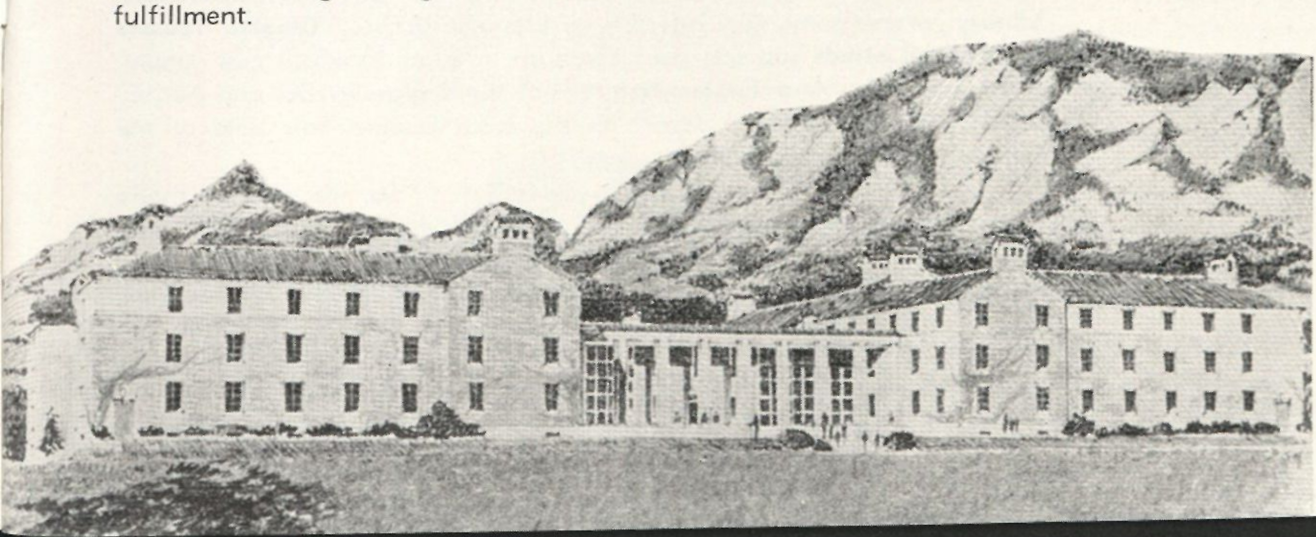
Entered as second-class matter March 9, 1916, at the Post Office at Boulder, Colorado, under the act of March 3, 1879.

Features . . . .

Humor? . . . .

Sections . . . .

Our cover suggests the significant role of professional, social and service activities in egineering fulfillment.



Loose Leaves

from the editor's notebook

With this writing, we bid a fond adieu to the hallowed halls of Ketchum. We take leave of four long years of cramming at midnight for the test we will flunk tomorrow. We say farewell to FAC at the sink. We remember classes dull and interesting. We think of the lifelong friendship formed. Of three meetings on the same evening with two hourlies the next day. And most of all, of the many things learned, both in class and out. And so, alma mater, farewell.

And as we wipe the tears from our eyes, let us first congratulate Lowell Brooks and Ron Steinberg and wish them the best of luck with the magazine next year. We know that all the students will support the **Engineer** as in the past and we hope that it will continue to be the true voice of the College of Engineering.

Now, for the matters at hand. As you delve into this issue, you will notice that it salutes the many activities of Engine School. The cover depicts a balanced student, one with academics and activities. Inside, you will find an article which salutes twelve Juniors and Seniors who were selected by an impartial committee as having contributed to the success and advancement of the College of Engineering by their extracurricular activities. Also in the spotlight is the staff of the **Engineer.** The individuals mentioned in this article have contributed much time to the success of the **Engineer** and deserve all plaudits possible. And, in the center of the magazine, you will find a photo-story of this year's E-DAYS.

For the technically minded, we present another fine article on low temperatures by D. K. D. Timmerhaus of the Chem.E. Department. Humor rears its ugly head with an article plagiarized from the **California Engineer** entitled **High Heel Wobble.** Now you can find out just how those sharp spikes can support a sharp shape.

And of course, we have business as normal with our sections. In **Alumnews,** you will read an interesting story of a CU graduate, living in the U.S., who was honored in a Russian photo magazine. **This Today** tells of some very interesting happenings in the world of science and technology. **For Your Library** reviews some very interesting reference books. **Tangled Teasers for Twisted Minds** subjects your cerebrum to stimulii which can supplement your $$$. And, **Engine Prep** tells of the Engine Physics and Aero.E. departments and gives a report on the state Science Fair held at the Bureau of Standards in April.

So, we wish to thank all for their help and support this year. It's been fun, interesting, challenging, and exasperating to produce the **Engineer.** We now pass the headaches on to the capable hands of Lowell Brooks. Good luck, Lowell, it's all yours.

Tom Clark

IMPORTANT DEVELOPMENTS AT JPL...

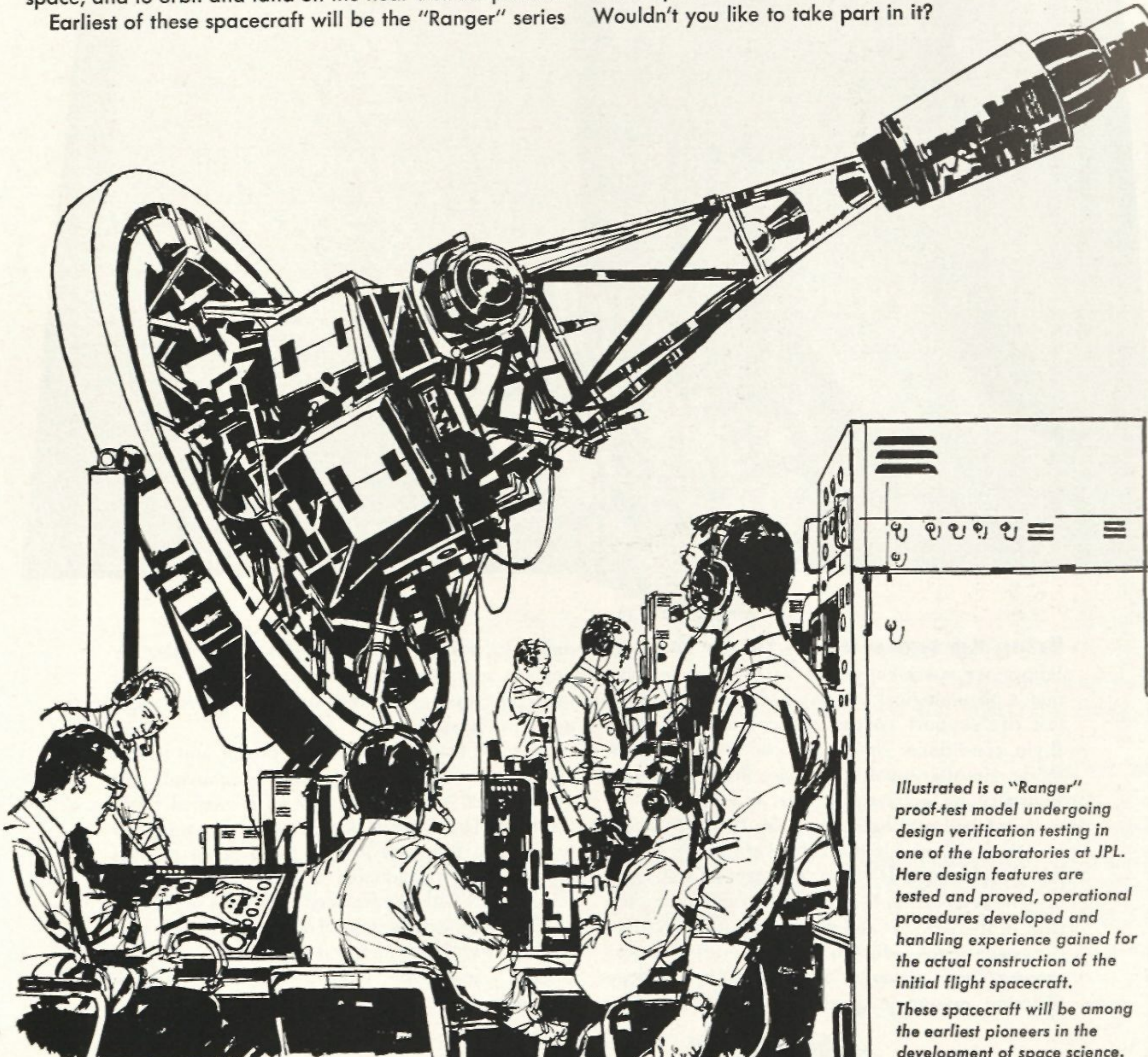
PIONEERING IN SPACE RESEARCH

The Jet Propulsion Laboratory has been assigned responsibility for the Nation's program of unmanned lunar, planetary, and interplanetary exploration. The objectives of this program are to contribute to mankind's fundamental knowledge of space and the space environment and to contribute to the development of the technology of space exploration. For the next ten years, as larger booster vehicles become available, increasingly versatile spacecraft payloads will be developed.

JPL will conduct the missions, utilizing these spacecraft to orbit and land on the moon, to probe interplanetary space, and to orbit and land on the near and far planets.

Earliest of these spacecraft will be the "Ranger" series now being designed, developed and tested at JPL. The mission of this particular series will include first, exploration of the environment and later the landing of instrumented capsules on the moon.

Never before has such a wide vista of opportunity, or a greater incentive been open to men trained in all fields of modern science and engineering. Every day at JPL new problems arise, new theories are advanced, new methods tested, new materials used and new principles discovered. This creates a stimulating work atmosphere for trained individuals and an unlimited field for constructive development of a long-range and rewarding career. Wouldn't you like to take part in it?



Illustrated is a "Ranger" proof-test model undergoing design verification testing in one of the laboratories at JPL. Here design features are tested and proved, operational procedures developed and handling experience gained for the actual construction of the initial flight spacecraft.

These spacecraft will be among the earliest pioneers in the development of space science.

JET PROPULSION LABORATORY

Operated by the California Institute of Technology under contract with the National Aeronautics and Space Administration

PASADENA, CALIFORNIA

Employment opportunities for Graduate Students in these fields

INFRA-RED • OPTICS • MICROWAVE • SERVOMECHANISMS • COMPUTERS • LIQUID AND SOLID PROPULSION • STRUCTURES • CHEMISTRY
INSTRUMENTATION • MATHEMATICS • ENGINEERING MECHANICS • TRANSISTOR CIRCUITRY AND SOLID STATE PHYSICS

Send professional resumé for our immediate consideration. Interviews may be arranged on Campus or at the Laboratory.

CRYOGENIC THERMOMETRY

DR. K. D. TIMMERHAUS and **JERRY GREEN,** (Ch.E. '61)

Introduction

Inevitably during any discussion of low temperature problems several related questions always seem to arise. These are:

(1) How do you measure temperatures under these severe conditions?

(2) Is there more than one method for measuring these temperatures?

(3) Under what conditions is one method recommended over another?

(4) What are some of the advantages and limitations of the various methods?

This paper will attempt to answer these and other questions and also hope to arouse the readers' curiosity both in this and other phases of cryogenics.

The accurate measurement of temperature, especially under cryogenic conditions, is not an easy task. Unlike properties such as length or volume, temperature can not be measured directly. It must be measured in terms of another property. The more important physical properties that have been utilized at this time for cryogenic thermometers include: (1) pressure of a gas; (2) equilibrium pressure of a liquid with its vapor; (3) electrical resistance; (4) thermoelectric emf; and (5) magnetic susceptibility.

The importance of choosing the thermometer or method which is most applicable to a specific situation often is not obvious. In some cases only one type of thermometer may be used. However, generally, this not true and the choice should be carefully considered with respect to the following characteristics: (1) accuracy; (2) reproducibility; (3) sensitivity; (4) stability; (5) simplicity; (6) Joule heating effect; (7) heat conduction; (8) heat capacity; (9) convenience; (10) cost; and others.

Various Temperature Scales

As noted above, the measurement of temperature is dependent upon a physical property of a substance. As a consequence, the resulting temperature scale is also dependent upon this substance. Thus Fig. 1 shows that a mercury in glass thermometer and various other thermometers, calibrated for the same range, will give the same values at the fixed points used for calibration but will differ substantially at intermediate temperatures. In order to overcome this difficulty Lord Kelvin introduced a temperature scale which was independent of the working substance. This scale is valid throughout the entire temperature range and is called the thermodynamic temperature scale.

Kelvin's thermodynamic scale is based on the concept of the Carnot engine. However, since the Carnot engine is merely a concept, not an actuality, it is necessary to measure the thermodynamic temperatures on the ideal gas scale. This is done by measuring the temperature with a constant volume gas thermometer and correcting the results for the non-ideality of the gas used. Extremely accurate temperature measurement with a gas thermometer, however, is very difficult and requires very costly equipment. Consequently in 1927 the Seventh General Conference on Weights and Measures adopted a new temperature scale referred to as the International Temperature Scale.

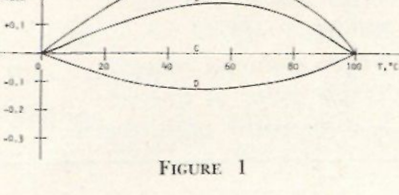


FIGURE 1

This scale did not supersede the Kelvin scale, but was adopted for its greater ease of reproducibility. This scale specified: (1) the values for the fixed points; (2) the types of instruments to be used in realizing the scale; (3) the equations to be used for interpolating or extrapolating from fixed points; and (4) the experimental procedures recommended. This scale was revised slightly in 1948 with the advent of more accurate measuring devices. The definition of this latter scale is given elsewhere.[1]

Table 1 lists the presently accepted standard and primary fixed points and the numerical intervals assigned to them. These values define the equilibrium temperature corresponding to a pressure of one standard atmosphere.

In addition to the standard and primary fixed points, a number of secondary fixed points have been established for calibration and other purposes.

As noted earlier the International Temperature Scale is defined by four fixed temperatures (below 630.50°C) and a formula which gives the temperature-resistance relation of a standard strain-free platinum resistance thermometer calibrated at these fixed temperatures. From the region of −183°C to the ice point the temperature-resistance relationship was given as

$$R_t = R_o\ [1 + At + Bt^2 + C\,(t\text{-}100)\,t^3] \quad (1)$$

where R_t is the resistance at the temperature t°C, R_o is the resistance at the ice point and A, B and C are constants determined by calibration at specified fixed points. Further details are given in reference.[3]

It will be noted that the International Temperature Scale does not extend below the oxygen point. Several attempts[4] have been made to establish a standard platinum thermometer scale below this point, but

Table I. Standard and Primary Fixed Points[2]

	Fixed point, temperature of equilibrium	Temp., °C	Temp., °K
Standard	Triple point of water	0.01	273.16
Primary	(a) Between liquid oxygen and its vapor (oxygen point)	−182.97	90.18
	(b) Between ice and air-saturated water (ice point)	0.00	273.15
	(c) Between liquid water and its vapor (steam point)	100.00	373.15
	(d) Between liquid sulfur and its vapor (sulfur point)	444.60	717.75
	(e) Between solid and liquid antimony (antimony point)	630.50	903.65
	(f) Between solid and liquid silver (silver point)	960.80	1233.95
	(g) Between solid and liquid gold (gold point)	1063.00	1336.15

in this region variations among different samples of platinum become much more serious than at higher temperatures, and this coupled with the difficulty of obtaining a satisfactory empirical formula for the resistance has resulted in several low temperature scales. One such scale between 11° and 90°K is the one in use by the National Bureau of Standards based upon the gas thermometric calibrations of a group of platinum resistance thermometers as established by Hoge and Brickwedde.[5] This scale has been used to calibrate the vapor pressure, triple point and solid-solid transition temperature of oxygen. Other low temperature scales that are of interest include those of the University of California, the Physikalisch-Technische Reichsanstalt and the Pennsylvania State University. A comparison of these scales below 90°K has been made by Scott[6] who found the maximum deviation from the University of California scale to be approximately 0.060°C provided all scales used the same fixed oxygen point.

Practical measurements of temperature in the range of 1° to 5° K are nearly always referred to the temperature scale based on the vapor pressure of helium-4. Here again, the existence of several liquid helium vapor scales has plagued the worker at low temperatures. However, by international agreement in 1958, a new scale designated as the T_{58} scale was recommended for general use. Values of vapor pressure vs. temperature in the T_{58} scale are given in [7].

The temperature scale below 1°K as used by most laboratories is based on a "magnetic scale." The temperatures here are usually denoted by T^* and are determined by measuring the magnetic susceptibility of paramagnetic salts and using Curie's Law to extrapolate to the very low temperatures. The procedure used in relating these magnetic temperatures to the absolute temperature scale will be discussed later.

Before discussing the various low temperature thermometric devices it may be well to consider a few selected "fixed" points of more immediate concern to the low temperature engineer or scientist. These fixed points are always liable to fluctuate in the light of further experimental evidence. However, their accuracy in terms of the thermodynamic temperature is probably as well known as the internationally accepted fixed points given previously in Table I.

Gas Thermometry

If the equation of state, that is the function relating pressure, volume, and temperature, of a gas is known, the gas can be used to measure temperature. If one of the variables is held constant and a second is measured, the third can be calculated from the equation of state. In thermometry it has been found most advantageous to hold the volume of a fixed amount of gas constant and measure the pressure. The temperature of the gas is then fixed. When properly corrected, such a constant-volume gas thermometer very closely approximates an ideal gas thermometer, and is used to fix points on the Kelvin scale.

In its most sophisticated form the constant-volume gas thermometer is the most accurate temperature measuring device available, and also one of the most expensive. Instruments which are accurate enough to be used to establish fixed points on the Kelvin scale are both complex and costly and hence, available at only a few large scientific centers. There are, however, many simpler forms of the constant-volume gas thermometer which are suitable for everyday laboratory calibration work. A few of these more inexpensive and practical types will be described in the following paragraphs.

One of the simplest forms of the constant-volume gas thermometer is the form used by Simon. (See Fig. 2). The bulb, which is at the low temperature to be measured, is connected by a fine capillary to a Bourdon type pressure gauge maintained at room temperature. The bulb has a volume V and the pressure spiral in the guage a volume v, which can be considered constant. The entire system is generally filled with helium gas at one atmosphere pressure.

Table II. Fixed Points Below 90°K

Fixed point	T, °K	Reference
Lambda point of helium	2.173	8
Boiling point of helium	4.215	7
Triple point of equilibrium hydrogen	13.81	9
Triple point of normal hydrogen	13.95	9
Boling point of equilibrium hydrogen	20.27	9
Boiling point of normal hydrogen	20.39	9
Triple point of neon	24.57	9
Boiling point of neon	27.17	9
Triple point of oxygen	54.36	9
Triple point of nitrogen	63.14	9
Boiling point of nitrogen	77.35	9

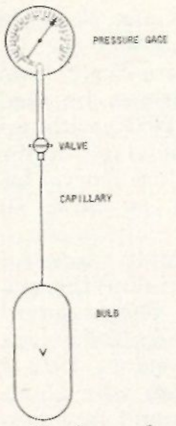


FIGURE 2

If the volume of the capillary is assumed to be negligible and if the gas can be assumed to be ideal over the temperature range to be measured, then the temperature is given by the equation

$$T = \frac{pVT_r}{p_r\,(v + V) - pv} \qquad (2)$$

where the subscript $_r$ denotes room conditions and p is the pressure in consistent units. This simple device can be quite accurate at low temperatures since then almost all of the gas will be in the bulb. At higher temperatures, however, a substantial amount of the gas will be in the volume v, and the thermometer will be rather insensitive to T. The sensitivity of this type of thermometer can be greatly increased at low temperatures by making v large in comparison with V. This results in a nonlinear gas thermometer for wide temperature ranges. At low temperatures the latter thermometer becomes more sensitive to T, but at higher temperatures it is more sensitive to room temperature T_r. If the ratio v/V is made sufficiently large, such a device can have an accuracy of $\pm 0.05\,^\circ$K at temperatures below 30°K.[10]

A more accurate and costly gas thermometer is the type which utilizes a mercury or oil manometer to measure the pressure. This is the most commonly used type, and there are as many variations of this type as there are laboratories. A very accurate adaptation of the constant-volume gas thermometer is the differential thermometer. As its name implies, the differential thermometer is used to accurately measure small differences in temperature. A good example of this type of thermometer is provided by White.[10]

A summary of the precautions to be observed with any one of these practical gas thermometers is given below:

(1) If a pressure gauge is used, it should be of precision quality with errors less than 0.1 per cent of full scale, and have a range of zero to about one atmosphere absolute. Care should be exercised to account for changes in atmospheric pressure.

(2) The temperature of the pressure guage or manometer should remain fairly constant especially if the volume of the thermometer bulb is comparable with the rest of the warm volume and the temperature being measured is relatively high. At very low temperatures the problem is not significant.

(3) A correction for contraction of the thermometer bulb may have to be made at temperatures above that of liquid nitrogen.

(4) Uniform bore tubing should be used to eliminate capillarity corrections.

(5) A temperature gradient in the connecting capillaries should be avoided; otherwise a difficult volume correction may be necessary to obtain reliable results.

If a gas thermometer is to be used for extremely accurate determinations, some additional corrections are necessary. A complete and rigorous treatment of gas thermometry corrections is given by Beattie.[11] It is beyond the scope of this paper to delve into the theory of these corrections.

Due to the difficulties inherent in gas thermometry, a more practical method of measuring extremely low temperatures has been devised. This method is based on the variation of the vapor pressure of a liquid with temperature over a limited range.

Vapor Pressure Thermometry

The pressure exerted by a saturated vapor in equilibrium with its liquid is a very definite function of temperature, and, as such, can be used to measure the temperature of the liquid. With a good pressure-measuring device, the vapor-pressure thermometer is an excellent secondary standard since its temperature response depends upon a physical property of a pure compound or element. Many formulas have been derived which relate the vapor pressure of a liquid to its temperature. These formulas are semi-empirical in that the constants must be determined experimentally. Tables have been published, however, giving vapor pressure as a function of temperature, and it is usually easier for most work to consult one of these tables rather than to use the formulas.

One of the great advantages of vapor pressure thermometers is their extreme sensitivity in the range over which they can be used. A temperature of 1 degree will result in a sizable pressure change. (See Table III). This great sensitivity, however, also leads to the one great weakness of the vapor pressure thermometer. It is good only over a very limited temperature range. These thermometers are accurate only in the area of the normal boiling temperature of the liquid used. The result of this is that several regions are inaccessable to vapor- pressure thermometry. For example, the range from 40° – 50°K is above the range of neon and below that of oxygen and nitrogen. Within its limits, however, this type of thermometer is very accurate.

The apparatus for vapor pressure determinations is relatively simple. There are many variations of vapor pressure thermometers, but one described by Scott and shown in Fig 3 will suffice as a common example. Any type of accurate dial gauge or manometer can be used and in the proper range great precision is obtained. For example, a mercury manometer which can be read to 0.1 mm will yield measurements that may be accurate to 0.0001 degree while a sensitive differential oil manometer may detect changes in temperature of the order of 10^{-5} degree.[13]

A special problem occurs when working with liquid hydrogen. Liquid hydrogen occurs in two forms,

Table III. Characteristics of Some Vapor-pressure Thermometers[12]

Material	Pressure=100 mm Hg		Pressure=760 mm Hg		Pressure=1000 mm Hg	
	T, °K	dp/dt, mm Hg/°K	T, °K	dp/dt, mm Hg/°K	T, °K	dp/dt, mm Hg/°K
Oxygen	74.5	15.9	90.18	80	92.9	95
Nitrogen	63.5	17.6	77.35	88	79.9	110
Parahydrogen	15.0	50	20.3	225	21.2	277
Helium	2.63	180	4.2	720	4.52	867

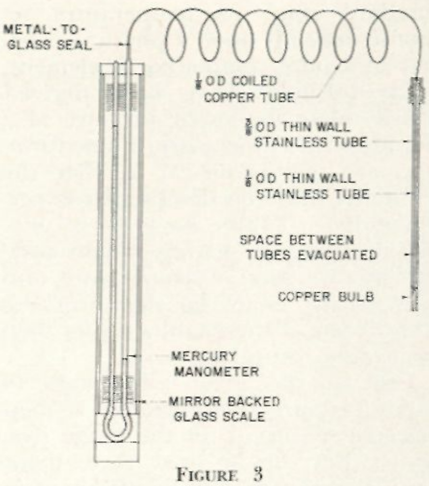


FIGURE 3

ortho and para. For vapor pressure determinations it is necessary to convert this to what is known as equilibrium hydrogen which consists of 99.8% of the para form. This conversion can be accomplished by using a suitable catalyst such as hydrous ferric oxide gel.

At low pressures the vapor pressure thermometer, like the gas thermometer must be corrected for the thermomolecular pressure. This effect can be minimized by using tubes ½ cm or more in diameter. Readings of vapor pressure recorded from a "liquid column" pressure gauge are subject also to gravity and temperature corrections. Another precaution that must be taken is to insure that the desired point of measurement be at a lower temperature than any of the surrounding apparatus.

The vapor-pressure thermometry equipment discussed to this point has been concerned primarily with laboratory instruments. It is generally not necessary to use a specific device to measure the temperature in a storage vessel or container since the vapor pressure of the boiling liquid is often used directly to determine the temperature of the surface. Tests have shown that there is a tendency for stratification of cryogenic fluids with a resultant increase in temperature with increasing depth. Convection helps to reduce the stratification tendency but it is often quite unpredictable causing erratic temperature readings.

Resistance Thermometry

Since the resistivity of an element or compound varies with change in temperature it has in many instances been used as a simple and reliable temperature measuring device. Many elements or compounds, however, are not suitable for use in low temperature resistance thermometry since they lack one or more of the desirable properties of an ideal resistance thermometer. These properties include:[14]

(1) A resistivity that varies linearly with temperature to simplify interpolation.
(2) High sensitivity.
(3) High stability of resistance so that its calibration is retained over long periods of time and is not affected by thermal cycling.
(4) Capability of being mechanically worked.

Resistance thermometers available today for low temperature work are generally weak in at least one of the above properties.

There are three general types of resistance thermometers: (1) pure metals; (2) alloys; and (3) semiconductors.

Pure Metals. According to Matthiessen's rule the total resistivity of a pure metal is given by

$$R_T = R_r + R_t \qquad (3)$$

where R_T is the total resistivity, R_r is the residual resistivity and R_t is the resistivity due to thermal vibrations. The residual resistivity is due to static imperfections such as chemical or physical impurities. The resistivity due to thermal vibrations is proportional to the temperature down to temperatures in the vicinity of a third of the Debye temperature (Θ^D). Below this R_t decreases more rapidly with temperature. Between $\Theta^D/10$ and $\Theta^D/50$ the resistivity due to thermal vibrations is proportional to the temperature to the n^{th} power where n is determined experimentally ($3<n<5$). The sensitivity is the first derivative of total resistivity with respect to the temperature, i.e., the slope of the R_T vs. T curve. For pure metals at very low temperatures this slope is quite small, resulting in poor sensitivity. This is a result of $R_r > R_t$ and it has been shown theoretically and expermentally by Sondheimer that Matthiessen's rule is not valid if such a condition exists. Consequently, it is desirable to have metals as pure as possible in resistance thermometers.

In the construction of a pure metal resistance thermometer it is important to remember that mechanical strain on a wire also increases its residual resistance. A good way to avoid this is to support the resistance element on the same material when it is being manufactured, e.g., nickel wire on a nickel spool. Another method that is quite satisfactory will be described later for a platinum thermometer.

Platinum thermometers are the best known and most reliable thermometers in use today. The standard one which is calibrated by the National Bureau of Standards defines the International Temperature Scale from −183°C to 630°C. It can be used to measure down to 20°K with accuracy; beyond this the slope of the resistance vs. temperature curve becomes almost constant, as shown in Fig. 4.

There are several highly successful types of precision platinum thermometers made today. The standard one in the United States today was first described by Meyers in 1932.[15] It consists of a platinum wire about 0.1 mm in diameter wound first into a helix of 0.5 mm outside diameter and then wound around a notched mica cross which is 40 mm long and 5 mm in height and width. This is annealed to relieve stresses and strains. The cross is housed in a platinum tube that is sealed with glass. For low temperature use the thermometer is filled with helium gas under a pressure of 3 to 4 cm of Hg at room temperature to insure good heat dissipation.

Platinum is considered to be a secondary standard for the temperature range from 20° to 90°K. Its principal advantage is that the purity of the metal can be reproduced from batch to batch. Its Debye temperature is relatively low and it is highly ductile. So far no other metal has been found which has a more favorable resistance-temperature curve. Its prime limitation is its inaccuracy below 20°K. The cost is also a factor since an NBS calibrated platinum thermometer costs around $900.

Indium has a Debye temperature of 100°K and has most of the characteristics of a good thermometric material. It can be obtained commercially with a purity of 99.999 per cent and can be extruded into wire as small as 0.25 mm. White and Wood[16] made a study of the resistance-temperature characteristics from its superconducting temperature of 3.4°K up to room temperature. The resistance of their thermometers went from 0.3 ohms at

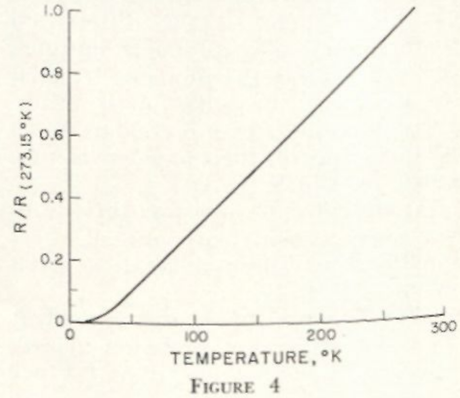


FIGURE 4

room temperature to 50 x 10^{-6} ohms at 4°K with an error of ± 0.25 per cent due to reading. The thermometers were found to be reproducible when cycled from room temperature to 77° and from 45°K to 4°K. Indium appears to be a very promising material for low temperature resistance thermometers but more research is necessary before its use will be widespread.

Other pure metals have been used for resistance thermometers. None, however, have proved to be as successful as the platinum resistance thermometer.

Alloys. In the preceding section on pure metals it was noted that impurities were the limiting restriction in many cases. This was caused by $R \simeq R_r$ which makes the resistance almost constant with temperature. This is true of alloys in most cases but there are a few important exceptions. They are: (1) anomalous alloys; (2) alloys exhibiting a resistance minimum at low temperatures; and (3) alloys with a superconducting component.

Manganin and Constantan are two alloys that show a large linear variation of resistivity in the temperature region from 2° to 20°K. A Constantan thermometer has a fairly constant temperature coefficient of approximately 0.001 per degree in this temperature range. Their main limitation is that they are not reproducible upon cycling to room temperature. They also are affected in a nonreproducible manner by magnetic fields.[17]

A minimum resistance appears in a large number of dilute alloys at temperatures from 25°K down. This phenomena was first discoverd by de Haas, de Boer, and Van der Berg (1934) in samples of very pure gold and is shown in Fig. 5.[17] A minimum resistance was later also noted in Mg, Ag, Cu, Al, Na, Ga, Mo, Co, and Ce. This has been attributed to the traces of impurity that are in the elements. The exact minimum depends on the impurities and the relative proportion of each. There are several alloys which have favorable resistance-temperature characteristics, and are worth mentioning at this time. One is an alloy of Cu + 0.056 atomic per cent iron and is useful in resistance thermometry for temperatures from 2° to 20°K. An alloy of Au + .01% iron shows a good resistance temperature relationship above 1°K. In general this phenomena has a limited use in thermometry for the following reasons:

(1) Uniformity between specimens is almost impossible.

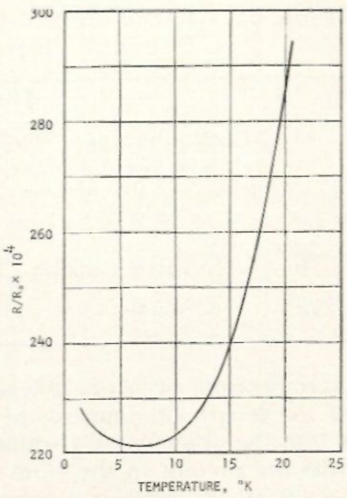


Fig. 5

(2) The minimum usually occurs below 7°K.

(3) External magnetic fields affect the readings.

(4) The sensitivity is usually very small.

Some metals become superconductors at low temperatures and when alloyed with other metals can produce anomalous effects which are useful for low temperature thermometry below 10°K. Two examples of this type are the leaded phosphor-bronze alloy and the leaded brass alloy.

A number of semiconductors also have useful thermometric properties at low temperatures. There are at least three distinct differences between semiconductors and pure metals as resistance thermometers. First, the sensitivity, $1/R\,(dR/dT)$, of a semiconducting thermometer in its useful range is usually much greater than that of a pure metal thermometer and increases with decreasing temperature. Second, the temperature coefficient of resistivity of semiconductors is negative while for pure metals it is positive; for example, the dR/dT for a typical semiconductor is $-50 \times 10^{-3}/°K$ at 273°K while platinum at the same temperature is $4 \times 10^{-3}/°K$.[18] Thus the resistance of a semiconductor decreases with increasing temperature while the opposite is true for a pure metal. Third, the resistivity is usually several orders of magnitude greater than that of pure metal. Consequently, a semiconducting thermometer element is usually short and of relatively large cross-section so that its resistance will be readily measurable.

A few semiconductor compounds such as $Zn0$ and Sn_20 have been investigated but their sensitivity, calibration, and cost have proved to be undesirable. The most promising semiconductors seem to be germanium, silicon, and carbon. The latter, though not strictly a semiconductor, is included in this group because of its similarity in behavior to semiconductors.

Very pure germanium has a resistivity which is too high for use at lower temperatures. Small amounts of an impurity are therefore added as a carrier to reduce the resistivity. Friedberg[19] produced a thermometer of poly-crystalline germanium which contained .001% indium which was reproducible to 0.001°K as long as the thermometer was not warmed to higher temperatures. Thermal cycling, however, occasionally affected the reproducibility and tended to displace the calibration curve parallel to itself. This defect seems to have been eliminated by Kunzler, Geballe, and Hull[20] who have developed a thermometer which consists of a single crystal of arsenic-doped germanium. Reproducibility was reported of the order of 10^{-4}°K at the boiling point of helium even after repeated cycling from room temperature to 1°K. A convenient working range for this thermometer was from 2° to 35°K.

The principal objections to germanium semiconductors as thermometers are: (1) the limited availability of suitable material; and (2) the lack of a simple mathematical expression for the resistance-temperature relation.

Carbon in one form or another is perhaps the most widely used of the high resistivity materials for low temperature thermometry. The most common carbon resistance thermometer used today is a carbon composition radio resistor manufactured by the Allen Bradley Company. Clement and Quinnel[21] have investigated these extensively and determined that the 1 watt size was the most suitable. Unfortunately, many carbon resistance thermometers experience the same reproducibility difficulties under repeated thermal cycling as do some germanium resistance thermometers. This seems to be caused by a reorientation of the carbon molecules causing a change in the resistance characteristics. Edlow and Plumb,[22] however, have found that some carbon resistors are very reproducible when cycled between liquid helium and room temperature if they are not exposed to the atmosphere.

Recent work with another group of semiconductors, namely thermistors, has shown about the same advantages and disadvantages as are found in the germanium and carbon resistance thermometers. Consequently the latter are to be preferred because of the greater calibration data available.

Either a potentiometer or a Wheatstone bridge is generally used in the accurate measurement of the resistance in a resistance thermometer. In the potentiometer, a standard resistor and the resistance thermometer are connected in series with a battery. Successive measurements of the potential drop across the two resistors, which carry the same current, then yields the resistance ratio of the two resistors and permits evaluation of the desired temperature. In the bridge method, the resistance of the thermometer element is measured directly. The National Bureau of Standards using a Mueller bridge with a standard four terminal resistance element has attained an over-all accuracy corresponding to 10^{-4} ohm.

A source of error most often encountered in resistance thermometry is the falure to have the temperature sensing element at the same temperature as the object being measured because of heat conduction along the leads.

Another possible error involves the thermal contact between the temperature sensing element and the surface being measured. This contact may be impaired quite seriously especially under rarified atmospheric conditions encountered either in vacuum work or in outer space.

Thermoelectric Thermometry

When both ends of two dissimilar metals are joined and their junctions are maintained at different temperatures a continuous emf is produced. Thermoelectric thermometry is entirely dependent on this discovery of Seebeck in 1821. In its simplest form it consists of a thermocouple of two dissimilar metals which develop an emf when the junctions are at different temperatures and an instrument for measuring the emf developed by the thermocouple. If the wires are homogeneous, the emf developed in the thermocouple circuit is independent of the length or diameter of the wires. On the other hand, if inhomogeneities are present in the wires and they occur where there is a temperature gradient in the wire, then an additional emf will be developed. Variation of this parasitic emf with temperature gradient changes may introduce a serious error into the reading of the thermocouple. However, it should be emphasized that no emf is produced by an intermediate metal as long as the junctions are kept in regions of constant temperature. It follows from this that great care in the selection of wire for thermocouples must be exercised to reduce the effect of inhomogeneities.

Various thermocouple combinations used at low temperatures are given below:

(1) Copper vs. Constantan
(2) Gold + 2.11 at. % Cobalt vs. Copper
(3) Gold + 2.11 at. % Cobalt vs. Normal Silver
(4) Iron vs. Constantan
(5) Chromel P vs. Alumel

Copper vs. constantan thermocouples, in spite of their large change in sensitivity with temperature, are probably the most widely used thermocouples for low temperature work because of their relatively good homogeneity. Fig. 6 shows the rapid decrease in sensitivity of the copper-constantan thermocouple with decreasing temperature. The problems of parasitic emf's in accurate thermometry are usually so important that they completely outweigh the problem of decreasing sensitivity. Another problem, however, which must also be considered here is the high thermal conductivity of the copper and its corresponding heat leak effect along the wire. This point was also emphasized earlier in connection with resistance thermometers.

The gold-cobalt vs. copper thermocouple produces a higher thermoelectric potential difference at low temperatures than the copper vs. constantan thermocouple. (See Fig. 6). However, since the gold-cobalt is an alloy it is more likely to have some inhomogeneities which will cause spurious emf's and affect the accuracy of the reading. Nevertheless there are applications where the larger emf more than compensates for the inhomogeneity disadvantage. This is in the measurement of temperature differences at low temperatures. Cost wise, the copper vs. constantan thermocouple is less expensive than the gold-cobalt thermocouple. However, with the price of gold-cobalt wire only $.30 per foot for a 5 mil or 36 gauge wire, even this thermocouple becomes rather inexpensive.

Gold-cobalt vs. normal silver thermocouples show a high thermoelectric power and a low thermal conductivity. The disadvantage of the inhomogeneities in both the gold-cobalt and the normal silver along with the instability of the gold-cobalt in heating are generally compensated by the high thermoelectric power.

Iron vs. constantan and chromel vs. alumel thermocouples have not been used very extensively in low temperature work even though they exhibit essentially the same thermoelectric power as the copper vs. constantan combination. (This similarity is evi-

Table IV. Thermoelectric Potential Differences in Microvolts for Several Thermocouple Combinations[23]

Temp. °K	Thermocouple Combination			
	Constantan vs. Copper	Gold-Cobalt vs. Copper	Iron Y vs. Constantan	Chromel P vs. Alumel
4°- 20°	57.8	171.4	59	41
20°- 76°	646.9	1562.5	805	616
76°-273°	5545.6	8123.2	8252	6182

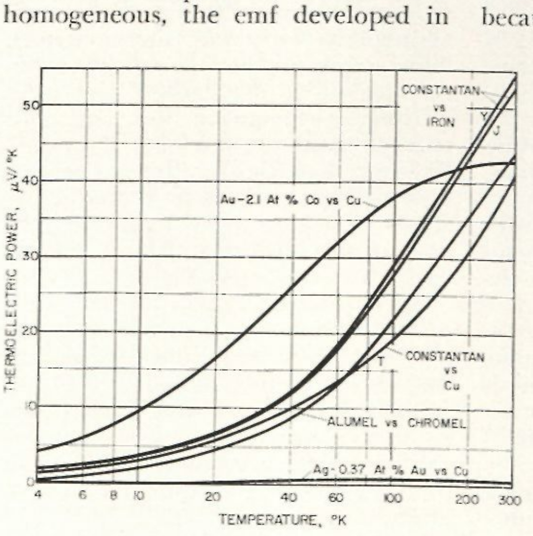


FIGURE 6

dent from Table IV.) The presence of inhomogeneities is once more the reason for the preference of the copper vs. constantan thermocouple over the former two.

For greater accuracy and sensitivity, thermocouples are often connected in series. It is apparent that a 2n-element thermopile produces n times the emf of a single thermocouple. In his book Scott[24] points out, however, that the temperature error due to inhomogeneities may be reduced by a factor of $1/n^{1/2}$ since many of the spurious emfs formed are just as likely to cancel each other. Thus the thermopile may serve as an effective way to get the arithmetic mean of the temperatures at a number of points.

Thermocouples, in general, are very simple and inexpensive to make. They can be easily installed in complex apparatus with little heat loss because of their low heat capacity. They are very responsive to temperature changes, fairly accurate over large temperature ranges, and can be read at a convenient location. However, in order to obtain the ultimate accuracy from a thermocouple, expensive measuring equipment must be used.

Since no two thermocouples, even with the same nominal composition, give the same relation between emf and temperature, each thermocouple must be individually calibrated. For thermocouples in common use it is customary to prepare a smoothed emf-temperature table by calibrating a representative thermocouple against a known source for many temperatures properly distributed over the entire range. Accurate deviations from this table may now be determined for any other thermocouple of the same nominal composition by calibration at only a few temperatures. The deviation curve often is nearly a straight line if the deviations in emf are plotted as the ordinate against the emf of the table as abscissa.

The proper installation of a thermocouple is many times just as important as the calibration. The most accurately calibrated thermocouple will not compensate for a poor thermal contact or a temperature gradient across a lead junction. The thermocouple must always be installed so that it registers the temperature of the region or object that is desired. Tempering of the thermocouple wires by bringing them approximately to the desired temperature at some distance from the cold junction is desirable and helps to eliminate heat flow along the leads to the junction. (This problem is most likely when one of the leads is copper). If this heat leak is not dissipated before it reaches the cold junction it would cause the thermocouple to assume a higher temperature than that of the surface to which it is attached. Good thermal contact is important especially in vacuum work and can be achieved by wrapping the thermocouple wires around the object and then cementing the thermocouple junction to the object. Epoxy resins have been used very successfully in this application. As a rule it is unwise to solder junctions to grounded surfaces since this increases the danger of spurious emfs caused by electrical leakage. By using a thin insulation it is possible to obtain good thermal contact and yet have the junction electrically insulated. Care with external circuitry is also essential for good thermoelectric thermometry. Connections with dissimilar metals should be avoided. Where they are unavoidable the connections should be in a region of uniform temperature. This precaution also applies to all external switches and contacts.

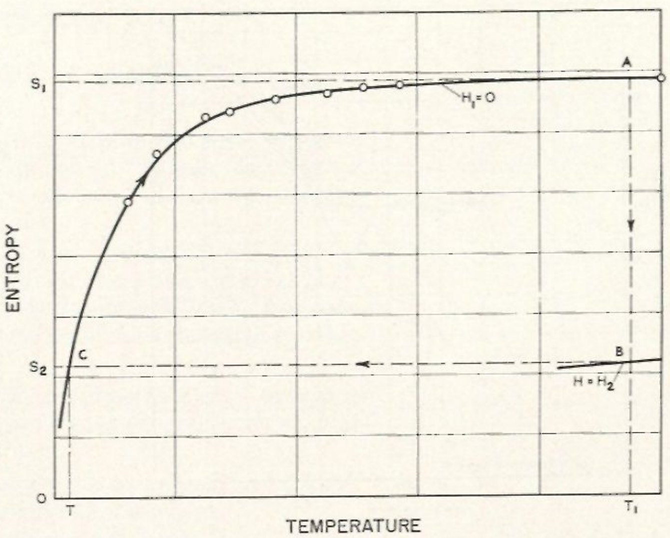


Figure 7

Magnetic Thermometry

Up to this point the discussion of low temperature thermometry has been involved with temperatures down to 1°F. This is essentially the lower limit of vapor pressure thermometry. To attain much lower temperatures, the method of adiabatic demagnetization of a paramagnetic substance as separately outlined by Giauque and Debye in 1926 must be used.

For a lucid explanation of the process of adiabatic demagnetization, consider the T-S diagram on Fig. 7 for a paramagnetic substance near absolute zero.

The process starts with the salt cooled to the initial temperature, T_1, without a magnetic field. This is represented by point A on the diagram. The entropy in this state is S_1. Increasing the field isothermally to H_2 brings the system to state B, where the entropy S_2 is less than S_1 since the state is more ordered. Then, insulating the system and decreasing the magnetic field to H_1 produces an adiabatic change to state C, where the entropy is still S_2, and the temperature T is lower than the original temperature T_1. The cycle may then be completed by a warming of the system back to state A along the curve CA. The temperature T may be determined by equating the entropy changes for processes A-B and C-A if the heat capacity and the change in the magnetization with change in temperature under constant field are known. This change is temperature from T_1 to T can be proved mathematically through the application of the Second Law using the temperature T and the magnetic field intensity H as independent variables.

Before dealing with experimental methods for the attainment of temperatures below 1°K, it is necessary to answer an obviously important question: How is the temperature determined within this range?

The helium vapor pressure thermometer below 1°K presents difficulties in accurate temperature measurements. Resistance thermometry has been used down to 0.1°K with carbon resistors and carbon strips on glass producing good results. Below this point, the only method of temperature measurement is magnetic thermometry, whereby the substance pro-

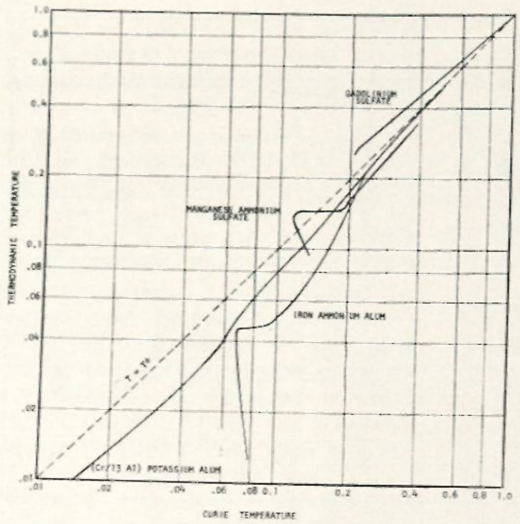


FIGURE 8

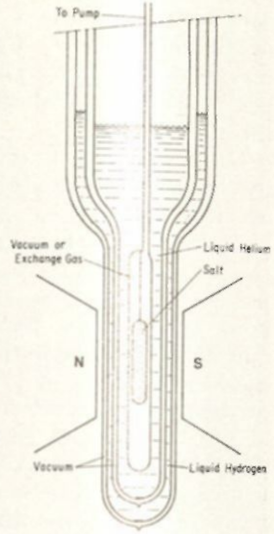


FIGURE 9

ducing the low temperature is its own measurement device. For this purpose an arbitrary temperature scale, known as the Curie scale, has been devised. The basis for this scale is Curie's Law, which states that the temperature is inversely proportional to the magnetic susceptibility:

$$T^* = C/X \qquad (4)$$

where T^* is the temperature in degrees Curie, C is a constant for each substance used, and X is the magnetic susceptibility. This relationship fails at extremely low temperatures, but for the materials used, it is sufficiently accurate that measurements may be made and then corrected for deviations from the law.

In order to convert from the Curie scale to thermodynamic temperatures, several methods have been proposed. These methods differ only in the experimental procedure to be followed, the thermodynamic principle for each being the same. At temperatures between 1° and 0.3°K the absolute temperature and T^* agree quite closely. Appreciable departure occurs below this as is shown in Fig. 8.[25]

The apparatus used in adiabatic demagnetization experiments consists of a unit in which a paramagnetic substance, usually a salt sample, can be cooled to temperatures near 1°K, magnetized isothermally, and demagnetized adiabatically. The demagnetization unit used by the Kamerlingh Onnes Laboratory in Leiden is shown in Fig. 9. In the operation of this apparatus the salt sample is cooled by liquid helium which is surrounded by liquid hydrogen. The hydrogen is present to absorb the heat leaking into the apparatus from the surroundings. The sample cools to the temperature of the helium surrounding the sample tube, which is near 1°K, since the helium is boiling under reduced pressure. Helium gas is then admitted into the sample space and the entire unit is placed between the poles of an electromagnet. The salt is then magnetized, with the heat liberated during this process being transferred to the liquid helium by the vapor in the sample tube. After magnetization, the helium is pumped out of the sample area and the magnetic field is removed. The salt sample, which is now thermally insulated from the rest of the system, cools adiabatically. The temperature of the system is found by means of the two coils inside the unit, which comprise an inductance. The magnetization of the salt is measured by these coils with the aid of an external balancing unit. The temperature found by this method is in degrees Curie.

A number of substances have been used in adiabatic magnetization studies. Among these are many salts of the rare-earth elements and a number of more common salts. The minimum temperature attained with the adiabatic demagnetization of a paramagnetic salt is 0.0014° $\pm$ 10 per cent.[26] This value was obtained by De Klerk, et al., in 1950 with a mixed crystal of chromium potassium alum and aluminum potassium alum.

While temperatures in the range near 0.001°K are extremely low, these are not the minimum temperatures which have been obtained to this time. The method for obtaining even lower temperatures is that of demagnetization of nuclear magnetic moments. The theory is similar to that for paramagnetic substances with the chief difference being that the nuclear magnetic moments are only 1/1000 as large as those of paramagnetic substances. The result of this change of magnitude is that magnetic fields 1000 times as large as those used in salt studies are necesary for the ordering of the magnetic dipoles. Numerous other difficulties are encountered in attaining temperatures in the micro-degree range.

However, these difficulties were surmounted in 1956 when a temperature of approximately 0.00002°K was obtained by Kurti, Simon, Robinson, and Spohr. In this experiment the nuclear spins in a mass of about 0.75 grams of copper were aligned by means of a strong magnetic field. The necessary conditions were achieved by contacting a number of small copper wires with a paramagnetic salt sample in the form of a slurry. The slurry was cooled adiabatically to a temperature of 0.01°K. The wires were then cooled to this temperature by heat conduction out of the wires into the slurry. The wires were then magnetized, with the heat produced in this process also being transferred into the slurry. Then, upon the removal of the magnetic field, the temperature of the wires fell to approximately 0.00002°K. Recently Kurti[27] has announced the attainment of a temperature of 0.000001°K.

Conclusion

One of the most difficult engineering problems in any field is the accurate measurement of temperatures. In principle, any physical property which is a function of temperature can be employed for temperature measurement. In practice, however, the list is greatly restricted by the requirements of the specific application. Thus for the measurement of low temperatures the thermometers usually employed fall into the following categories: (1) gas thermometers; (2) vapor-pressure thermometers; (3) thermoelectric thermometers; (4) resistance thermometers; and (5) magnetic thermometers. This paper has discussed the uses, ranges, advantages, limitations, and precautions of these five thermometers under cryogenic conditions.

(Continued on page 46)

HIGH HEEL *Wobble*

By CHUCK WAHL

This article is respectfully dedicated to all of the coeds and other members of the opposite sex who gave so generously of their time and talents in the interests of science and the pursuit of knowledge. They often served at rather late hours and under trying conditions, but without their whole-hearted cooperation this article would not have been possible.

For years, since the advent of the custom known as social dancing, one problem has remained foremost in the minds of engineers. This problem deals with the means by which a member of the female species engages in this custom—her foot-covering or shoes.

There are many types of shoes which are worn to special dances, among which are Keds, slippers, flats, high heels, and spikes. These last two types are by far the most important. Generally they are worn only for the dressier occasions when maximum appeal is being made to the male ego. The best way to differentiate between spikes and high heels is to have a subject walk on a modern moving escalator using the shoes in question. If the heels of the shoes become embedded in the steps of the escalator, the shoes are spikes; if they do not, the shoes are ordinary high heels. Unfortunately, the mortality rate among the subjects wearing spikes is rather high which makes this method of testing somewhat impractical. For our purposes the silhouettes below would suffice in showing the difference between spikes and high heels.

Figure 1

The basic problem concerning high heels, or spikes, as the case may be, is to determine the inherent heel wobble present in high heels while dancing. Since the first public appearance of high heels, this problem has puzzled the best of engineers. We hope that the results of this research will enable others to eliminate the annoying vibrations encountered when dancing with a girl shod in high heels, for it is these vibrations which prevent the establishment of a stable state of equilibrium and close relations.

Optimum Conditions

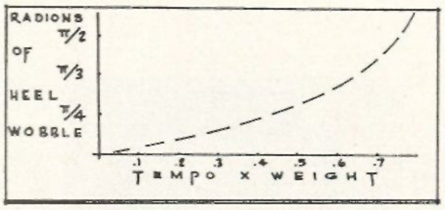
Ideally, the conditions necessary for the determination of high-heel wobble would be the following: one twenty-piece orchestra capable of playing slow or fast music superbly with or without blindfolds; one isolated room completely void of any outside interruptions, equipped with a smooth dancing area of at least four hundred square feet, an automatic temperature control and an automatic internal indirect lighting system whose brightness varies directly with the intensity of the music; an analog computer; a typical engineer; and a ravishingly beautiful brunette suitably attired and somewhat shorter than the engineer.

In actual practice these conditions must be altered considerably to accommodate the use of inferior but nevertheless readily available components, such as: a three-speed record player and several albums of records; an empty living room; several fellow engineers and a protractor; a typical engineer; and a college coed. In addition a pair of four-inch spike heels with spike length adjustment, helmets, and steel-toed shoes are needed.

Collecting Data

While the couple dances, the extraneous engineers should be busily occupied in measuring the angle formed when the heel comes into contact with the floor. However, no data should be taken until the engineers become adept at dodging the deadly high heels. In the case of spikes, the wounds inflicted can be mortal. To make the situation as general as possible, a few pieces of classical music should be included among the record albums to serve as a control on the different types of dance music. Each type of music should be played at each of the three speeds on the record player: 78, 33⅓ and 45 rpms. The mass of data introduced by this variation in speeds is neecssary to provide more points from which to calculate. If a four-speed record player can be obtained, it should be used. The addition of 16⅔ rpm speed oftentimes provides some very interesting results. Since changing the speed may cause extreme confusion on the part of the dancers, it is wise to choose people who are very adaptable.

Several years ago a group of curious engineers headed by Doctor Ann Nonamus did some research on the subject of high-heel wobble. They succeeded in plotting the rough graph of Radians of Heel Wobble versus Tempo times Weight shown below.



Curve showing the results of the experiments.

Figure 2

In addition they obtained an experminental equation for the amount of wobble in radians:

$$\text{Wobble (radians)} = \frac{(1/s + M^2 + ht/10)\ L}{(t + hp + a)\ F}$$

Their equation

Figure 3

where s = shoe size
h = height (feet)
t = music tempo
L = length of heel (inches)
M = mass
hp = height of partner (feet)
a = area of heel (square inches)
F = finagle factor

This equation very logically shows that the amount of wobble incurred is directly proportional to the length of the heel and inversely proportional to the resultant area of the sole in contact with the floor. In our experimental work there were several places where their original equation broke down. First of all, since mass is reasonably constant, it can be considered a proportionality factor. Secondly, we found that the graph is more nearly correct when we consider the summation over a closed interval. Thirdly, we found that there were three other factors which had a direct bearing on the equation itself. They are: d, the distance between the couple; M_s, the marital state of the couple; and D, the type of dress worn by the female. Therefore our revised equation is as follows:

$$\underset{(\text{radians})}{\text{Wobble}} = M^2 \int_{\text{Slow}}^{\text{Fast}} \int_{\text{Short}}^{\text{Tall}} \left[\frac{\frac{1}{s} + \frac{ht}{10}}{t + hp + a}\ L\ \frac{dM_s}{D} \right] dh\, dt$$

Figure 4

Revised Equation

where d is measured in millimeters and D and M_s have certain constant values for individual cases. A table of the various combinations appears below.

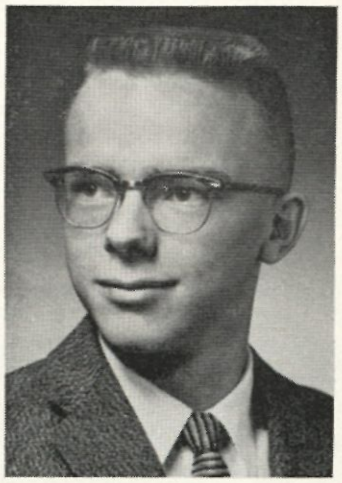
Type of Dress	Value of D	Marital State	Value Ms
Sheath	392	First Date	828
Cocktail	246	Third Date	717
Formal (semi-ruffly)	241	Semi-	17
Formal ruffly)	38	Steady	10
Formal (floor length)	Unknown	Lavalier	5
		Pinned	2
		Pinned	2
		Engaged	1
		Married	0

The findings we have presented here are by no means exhaustive. This is a relatively new branch of mechanics and there are still many unanswered questions. But in this one field, at least, pure science has finally come into its own; the material compensations for research in this area are almost immediately forthcoming.

—Courtesy of The California Engineer

The *Colorado Engineer* announces

OUTSTANDING ENGINEERS



DENNIS GRAUE is a 21 year old senior in chemical engineering. During his four years at the University, Dennis has been active in the American Institute of Chemical Engineers, the Society of Military Engineers, Alpha Chi Sigma, AES and AES Control Board; Engineers' Days, Tau Beta Pi, Sigma Tau, and Phi Lambda Upsilon. Dennis, or D.J., has received, among other honors, the Beginning Physics Achievement Award, AIChE Sophomore Chemical Engineer Award for highest scholarship, the Tau Beta Pi Honor Junior Award, and the L. E. Whitlock and Standard Oil of California scholarships. Upon graduation in June, he plans to work for the DuPont Company for the summer. In the fall he will continue his education to achieve an advanced degree at the California Institute of Technology under a National Science Foundation Fellowship. Dennis, when asked for a comment about his past four years of undergraduate study, said, "What I feel is most important in school is to take your education seriously, and to put the effort into the academic and professional phases which you owe yourself."

GEORGE STRECKER is completing his degree work in combined electrical engineering and business. This 23 year old senior has been President of the AES, General Chairman of Engineers' Days, President of Tau Beta Pi, Assistant Business Manager and Section Editor of the *Colorado Engineer*. In addition he has participated actively in Slide Rule Follies, AIEE-IRE, Eta Kappa Nu, and Sigma Tau. Presently George is an instructor in the Applied Mathematics department and has an overall grade point average of 4.00. George plans to attend a graduate school, probably Tulane, to work for an advanced degree in mathematics. College teaching is indicated as his eventual field of endeavor. George, when pressed for a comment, urged all students to take courses of a controversial nature that don't have pat answers, so that research will help you develop answers.

Dave Green is a 22 year old student in the combined program of Architectural Engineering and Business. To broaden his education, Dave has been president, treasurer, and historian of Sigma Tau, treasurer of Pi Epsilon, secretary of Tau Beta Pi, and active in the AES. Dave has also received a Tipton Scholarship for an extra year of non-technical study at the university. Presently Dave is an instructor in the Applied Mathematics department and plans to spend this summer working for Proctor and Gamble. Dave believes that the engineering students in particular should "apply themselves and take part in activities which are a very important part of college life."

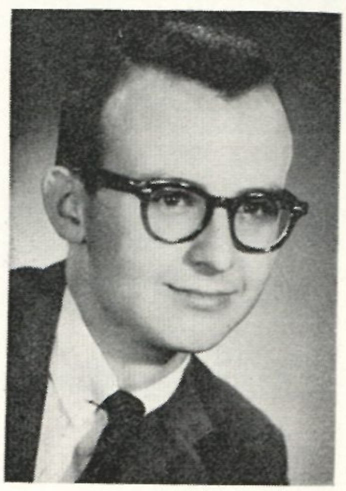
Troy Martin is the 27 year old AES Finance Councilman on this year's AES Council. While working as a half-time research technician in the Physics Department, Troy has found time to be the president of Eta Kappa Nu, treasurer of AIEE-IRE, and an active member of Tau Beta Pi and Sigma Tau. In his spare time Troy has managed to pick up a 3.4 overall grade point average in Electrical Engineering and Business. Upon his June graduation, Troy plans to work for the IBM Corporation in San Jose, California, setting up a central instrumentation department. Troy urged the students to "Stress activities due to industry's interest in them."

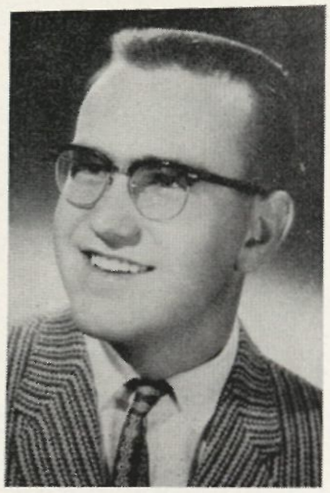
Lowell Brooks, recently selected as next year's editor of the *Colorado Engineer,* is a junior in applied mathematics. He has been a writer on the *Colorado Engineer* and is presently the section editor. Tau Beta Pi and Sigma Pi Sigma both claim Lowell as a member. As a freshman he won first place in the Analytic Geometry Competition and last year he shared a three-way tie for first place in the Calculus Competition. This summer he will participate in the undergraduate research program at C.U. under the direction of Mr. Frank Krieth, probably in the field of differential equations. Lowell plans to continue his education to obtain a master's degree after his graduation.

Thomas Clark, this year's editor of the *Colorado Engineer,* is an Engineering Physics major. Besides being a writer and section editor for the *Colorado Engineer,* Tom is a member of Tau Beta Pi, Sigma Tau, Sigma Pi Sigma, American Institute of Physics, and the Radio Club. Tom is planning to attend graduate school upon his graduation from the University in June to major in Astro-Geophysics. In the meantime he plans to work for the National Bureau of Standards in Radio Astronomy.

Dan Sutherland has combined active participation in other than scholastic pursuits with scholastic prowess to earn a 3.7 overall grade point average in Mechanical Engineering. This 21 year old senior has been secretary of Tau Beta Pi, president of Pi Tau Sigma, vice president of ASME, and a member of Sigma Tau, and the AES Control Board. After his June graduation, Dan plans to enter the Illinois graduate school to work for a Masters Degree in Mechanical Engineering.

Marshall Gurian, this year's Chairman of the Engineers' Days Band, is a chemical engineering student who plans to graduate next February and then enter graduate school in chemical engineering the following September. Marsh has been active in both all college and society activities. As president of the AIChE, he was a delegate to the national convention. Marshall has also been co-chairman of Slide Rule Follies, President and Master of Ceremonies of Alpha Chi Sigma, Secretary of Sigma Tau, and is presently a Tau Beta Pi pledge. In addition he has managed a 3.4 overall grade point average. Marshall believes that a grading system should be uniform and used as a stimulus, and not mis-used as is presently the case in many instances. He feels that a grade point is next to meaningless as an evaluation of performance.





Al Anglund is a junior mechanical engineering with a 3 point grade average. Al has been very active in his few years at this institution as he has been the Secretary of the ASMe, Secretary of Pi Tau Sigma, Vice President of Sigma Tau, Special Events Chariman for Engineers' Days, AES, and a participant in the undergraduate research program under the aid from the National Science Foundation. Al plans to continue at C.U. to obtain his master's degree in mechanical engineering, later to obtain his doctorate at some other university. Al stated, "I feel that education is a dynamic process. Not only must the student be dynamic in scope, but must be dynamic in participation. There is a direct proportionality evident between laziness and failure. We, as engineers, need to appreciate culture and moral and social values as we hold the tool of human destruction and must use it to further the freedom and ideals of America. Upon our decisions lie the fate of the world, we must make the right one—Freedom for all."

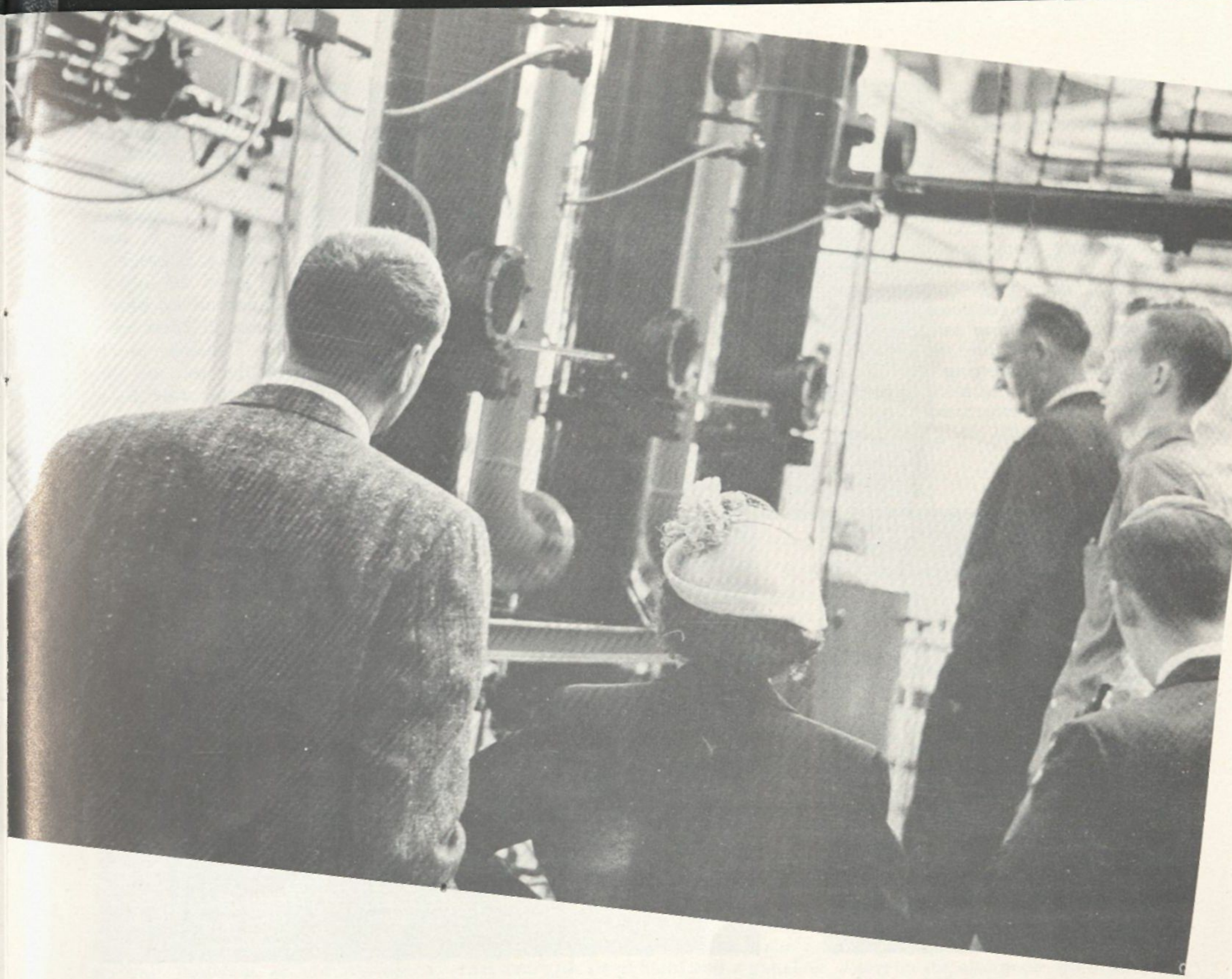
Jack Bishop, Jr., this year's *Circular File Editor* for the *Colorado Engineer*, is a senior chemical engineering student. Jack has participated widely in the activities of the college. His past work includes Activities Councilman for the AES Council, Humour editor, section writer and contributor for the *Colorado Engineer*, Special Events Chairman and General Chairman of Engineers' Days, Co-General Chairman of Slide Rule Follies, Vice President of Alpha Chi Sigma, and member of the AIChE.

Jack plans to enter private industry after his June graduation in the field of technical sales or related work. Jack believes that "not all of a student's education can be found in the classroom, and for that reason universal participation and interest in the engineering activities, both as a service to yourself and the college, is necessary."

Frank Perrino, the vice-president elect of the AIEE-IRE, is finishing his fourth year in the combined program of Electrical Engineering and Business with a 3.4 overall grade point average. Frank has been the historian of Delta Sigma Pi, is a Tau Beta Pi pledge, and has been very active in Eta Kappa Nu and the Slide Rule Follies, in addition to his AES membership. Frank's future plans, which include his wife, 4 year old son, and 2 year old daughter, lean in the direction of solid state work and possibly sales engineering. Frank believes that the College of Engineering is progressing, and that the program for the bachelor's degree in engineering should be expanded to a five, rather than a four, year curriculum. Frank believes that this extension is necessary as many graduates do not take additional course work in their field and the extent of the fields has increased to make this further education necessary.

Ellwyn Erickson, a 23 year old aeronautical engineering fifth year student, has a 3.5 overall grade point average. Ellwyn has been president of Sigma Tau, vice president and secretary of the Institute of Aeronautical Sciences, cover editor of the *Colorado Engineer*, and an active member of Tau Beta Pi and AES. Ellwyn plans to return to school in the fall to begin his graduate work in the field of political science. For his future career, Ellwyn is considering the Army Intelligence Corps. As an instructor in the Applied Mathematics department, Ellwyn has had much experience with the entering students and stated that he "feels that a more serious approach must be presented by instructors to the new freshmen as to what should be expected of them, as the freshmen are often inadequately prepared." He also suggested that the new students and present students "must think about a wider education than their engineering specialization, since everyone needs a broad range."

(Continued on page 46)



ENGINEERS' DAYS

In May of every year, the students of Engine School take time from their studies to celebrate their annual Engineers' Days. During this time the engineering student honors outstanding members of his college, learns more about his field in the departmental seminars, shows his school to prospective engineering students, and has a little fun at the E. Days Picnic and Ball. Through the combined efforts of members of the *Colorado Engineer,* we now present a review of the 1961 Engineers' Days.

Convocation

Students trod across campus to Macky Auditorium, May 5, under a gray sky in a heavy downfall of rain. The outgoing Associated Engineering Students President, Dennis Hicks, welcomed the students. Dean Hutchinson hastily but efficiently gave the scholarship and memorial awards and recognitions. Keys were given to the newly elected Associated Engineering Students' officers for '61-'62, James N. Counter III, Don G. Ellis, Larry D. McGee, and Larry R. Houge. Lowell W. Brooks and Ronald L. Steinberg also received keys as the in-coming editor and business manager, respectively, for the *Colorado Engineer.*

William J. Hanna, associate professor in the Electrical Engineering department, was the recipient of the Associated Engineering Students' Faculty Appreciation Award.

The Colorado Engineering Council chose to award its silver medal for the outstanding senior to George E. Strecker, a five year student in Electrical Engineering. As runners-up, Louis O. Cropp, a Mechanical Engineering major, and Dennis J. Graue, a Chemical Engineering major, received certificates of merit.

Keynote speaker, James M. Ewell, recently named to the Board of Directors of Proctor and Gamble, addressed the Engineers' Days convocation on "The Dynamics of Engineering." Mr. Ewell is a graduate of Massachusetts Institute of Technology, receiving his B.S. in Chemical Engineering in 1937. Since then he has been an employee of Proctor and Gamble. In 1955, Mr. Ewell was promoted to Vice-President of Manufacturing. In 1958, he acquired his present position of Vice-President of Manufacturing and Employee Relations.

Mr. Ewell cited the development in the engineering field today. He pointed out that "Engineering is a live, growing profession" which is in a constantly changing dynamic state --both in width and breadth. For instance, after graduation the engineer is no longer restricted to straight engineering but may utilize his education in one of four ways: product engineering, engineering of plant and facilities design, technical sales and writing, and management. The first two ways represent straight engineering, while the latter two stress personal relations.

In this ever changing realm, there has been an evolution of a third man in our scientific world. Besides the scientist and the engineer, an engineering technician has come into existence. Mr. Ewell explained that the task of an engineer is gathering scientific facts, laws, and developments, then applying, using, and controlling them. However, the engineering technician develops the detailed engineering designs. The key to entire and full engineering progress, as set forth by Mr. Ewell, is the role of the scientist, engineer, and engineering technician.

As a closing thought, Mr. Ewell emphasized that the background engineers receive in school is only a beginning and that in order to make a success of his career, motivation is essential. He pointed to the fact that today an engineer is a well regarded and an appreciated member of society. The engineer today, is assigned responsibility early, given the opportunity to make important decisions, and given the chance to enter into business. He stated "dynamic" is an understatement of the role of the engineer and that this role is a challenge to those entering the engineering field.

Mr. J. M. Ewell

George Strecker receiving Outstanding Engineering Award

Seminars

Friday afternoon was set aside to further the engineers' knowledge in a relaxed out of the classroom atmosphere. The departments in the College of Engineering separated into groups for discussions of interest to their individual fields. The Aeronautical Engineering Department presented Dr. George Gamow, Professor of Physics, University of Colorado, whose talk was entitled "Chemical and Nuclear Rockets."

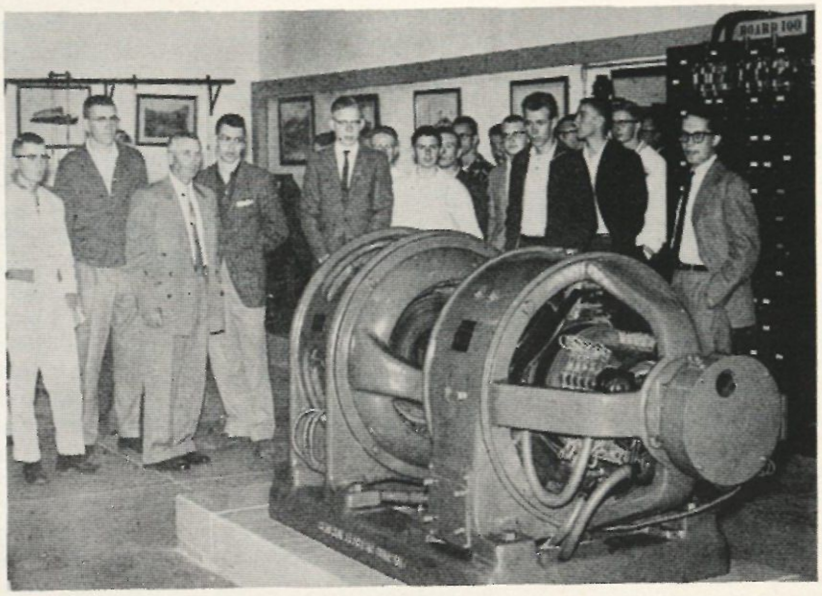
The Architecture Department held a panel discussion on "The Future of Architectural Character of The University of Colorado." The panel included: Mr. W. C. Muchow, a Denver Architect; Mr. H. D. Wagener, a Boulder Architect; and Professor C. A. Briggs, of the University of Colorado, who acted as moderator.

Mr. E. L. Mosley, of the Denver Board of Water Commissioners, talked to the Civil Engineering Department on "The Roberts Water Diversion Tunnel." The Chemical Engineering Department held two seminars. The first was by Mr. George Lof, a Consulting Engineer, "Development of Solar Energy." The second was by Dr. Walter Weir, Director of the Honors Program at the University of Colorado, "The Engineer in Society."

The Electrical Engineering Department was host to Mr. Carl Stuehrk, of AT&T, whose talk was titled "Engineers in Management." The Mechanical Engineering Department presented Dr. R. C. Mercure, Jr., Director of the Ball Brothers Research Corporation. His talk was "What an Engineer Should Know."

Banquet

The banquet was a complete success, as the hundred people who enjoyed the excellent food and wonderful entertainment can attest. It was a pleasant surprise to find the long-winded speeches usually accompanying these affairs replaced with a capable singing group, the Mario Singers. This group which sings regularly at Mario's of Aspen in Denver, entertained the guests with selections from various Broadway musicals and operettas. Those who attended seem to agree that the banquet afforded a good evening's entertainment.



High School Students

Eye Our Mechanical Monster

High School Convocation

The second day of E-Days 1961 began by introducing the future University of Colorado engineering students to the campus. They started their day with a meeting in the physics building that included several introductory speeches. Jack Bishop, master of ceremonies, introduced Dean Stahl, who welcomed the students and their parents, after which Mr. Hanna, associate professor in the Electrical Engineering Department, congratulated the boys for having considered engineering as their vocation. He also told them a few of the advantages of becoming an engineer. Following Mr. Hanna, Dennis Hicks, retiring President of the Associated Engineering Students, spoke to them on the advantages of coming to the University of Colorado. He pointed out that this was a good college from which to obtain a degree, as there are opportunities for good employment upon graduation, and here one could obtain a balanced education.

Following the introduction the students and their parents were divided into groups according to their prospective fields. These groups were then taken to the various engineering laboratories for a briefing on requirements in their fields and for demonstrations.

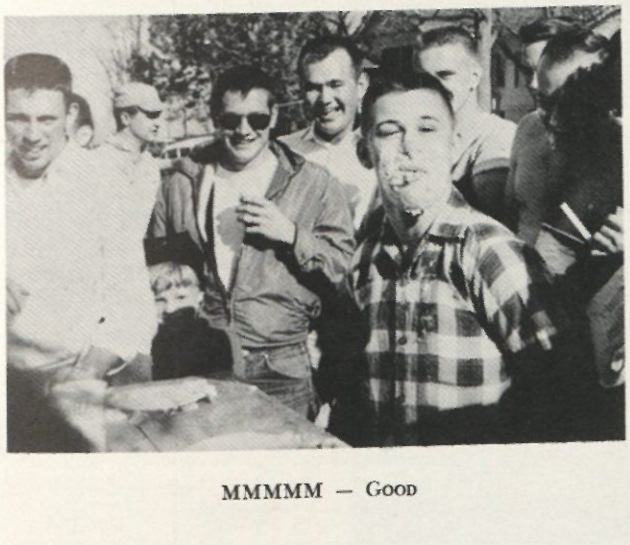
The mathematics placement test was given for the two remaining hours before lunch. While the students were taking the test, the parents met with Dean Stahl and a panel of four engineering students to answer any questions that they might have.

Many of the visitors ate lunch in the University Memorial Center after which they met on the terrace with Alpha Phi Omega for a tour of the campus, the residence halls, and the R.O.T.C. labs. To end their day the students were taken to the cyclotron.

Field Events

In marked contrast to last year's weather, the skies were clear and blue Saturday. So at 11:00 the engineers gathered at Chautauqua Park in South Boulder to continue their celebration via the annual Engineers' Days Picnic. In keeping with traditions of the past the picnic started with a fine lunch followed by free beer (or vice versa).

Later in the afternoon, the students of the applied sciences pitted themselves against one another in various tests of skill known as the E. Days



MMMMM — Good

Wow!!

field events. As the events progressed, it became increasingly evident that the civil engineers were in rare form. They took first in the Egg Toss, the Tug-o-War, the Four Legged Race, the Bat Race, the Pie Eating contest, and came in second in Soft Ball. The M.E.'s also made a strong showing, taking second in the Tug-O-War, the Egg Toss, the Bat Race, the Four Legged Race, and placing first in Soft Ball and the Participation Poll. The other first of the afternoon went to the *Colorado Engineer* in the Beer Chuggin contest, which ought to say something for this magazine. Naturally enough, when the points were totaled it was found that the civil engineers had won the field events with a total of 30 points. The actual highlight of the afternoon's activities, however, was the Miss Most Perfect Body Contest. After much deliberation our very qualified judges gave the award to the lovely Miss Judy Herschberger.

Final Results of the Field Events

Event	1st	2nd	3rd
Egg Toss	C.E.	M.E.	Colo. Eng.
Four Legged Race	C.E.	M.E.	E.E.
Tug-O-War	C.E.	M.E. & Aero.	
Soft Ball	M.E.	C.E.	
Bat Race	C.E.	M.E.	
Participation Poll	M.E.	Colo.Eng.	C.E.
Pie Eating	C.E.	Chem.E.	M.E.
Beer Chugging	Colo.Eng.	E.E.	M.E.

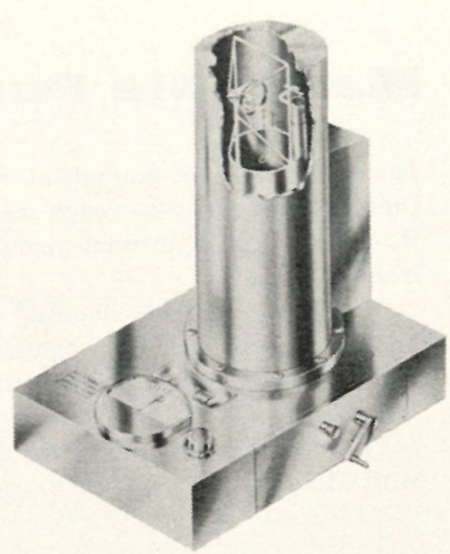
Engineer's Day Ball

Highlighting the weekend was the Engineers' Ball held in the Glenn Miller Memorial Ballroom of the UMC. The theme "Exotica," was adeptly carried out with sweeping bands of blue paper, delicate clouds of angles' hair, and exotic tropical plants. The presentation of the field events trophy to the civil engineers was followed by the crowning of the Queen. That is, after a small delay. It seems that Chi Epsilon had taken it upon themselves to "borrow" the queen candidates for the evening. However, after being awarded the honor of escorting the candidates to the stage they agreed to return the girls. So everything was fine—except a notorious group known as Alpha Omega (formed the Thursday before the Ball) had stolen the ballots. However, being the gentlemen that they were, they graciously awarded themselves the honor of announcing the Queen of the 1961 Engineers' Days, Sarah Kiser. Attending Sarah were Elaine Thielking, Lonnie Jean Anderson, Marlinda Mason, and Caroline Beach. After the crowning, M.C., R. R. Sandusky, awarded himself the honor of dancing with the Queen to the music of Tasso Harris. All in all it was a very awarding evening (if you'll pardon the pun) and a delightful climax to the 1961 Engineers' Days.

E. Days Queen

Sarah Kiser

COLORADO INDUSTRIES



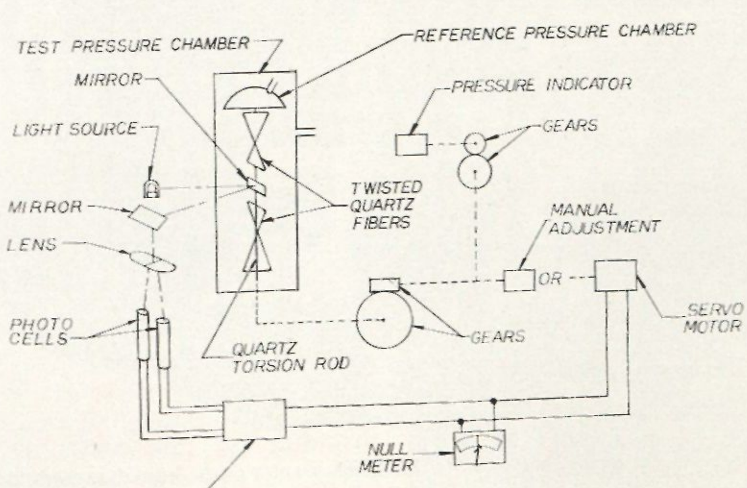
JAY BLISS, (M.E. '63)

The Buck Instrument Company, located in Boulder, is currently limiting production to two precision instruments. Both are interesting and unusual, and merit the attention of the engineer. Although the company is equipped to produce other instruments, their pressure gauge and their turbine-driven mirror used in framing cameras receive most of their attention.

The common conceptions of the mechanism comprising a pressure gauge must be altered to understand the operation of the Buck gauge, as the extreme accuracy (readings within one micron pressure) necessarily demands a greater complexity. For one thing, the entire sensing unit is of fuzed quartz, as this material has no measurable hesteresis, and will not introduce inaccuracies from fatigue. An electronic system accounts for the translation of pressure deviations to a visual scale.

As with a conventional gauge, there is an evacuated chamber with one surface designed to fluctuate with pressure variations. One end of a quartz fibre under torsion is fused to this surface, the other end is affixed to the center of a revolvable gear. Further gearing allows for a manual adjustment or a servo motor to vary the torsion on the fibre.

A mirror is located midway on the fibre; so any variation in pressure will vary the torsion via the flexible chamber surface and thus rotate the mirror in proportion to the change in pressure. At zero inches of mercury the calibration on the manual torsion adjustment will be zero, and the mirror on the quartz fibre will be in such a position that a light source will reflect light off it and another mirror onto two photocells. A meter indicates a zero null when the photocells receive the greatest amount of light. A variation in pressure will rotate the mirror, reflecting light away from the photocell so that it will not receive the full amount of light. The null meter will read the direction and extent of the mirrors deviation. To get a zero reading, the torsion on the quartz fibre is adjusted by the manual adjustment until the null meter reads zero. The gearing ratio on the manual adjustment is so designed that the amount of correction on the torsion of the rod is read on the calibrator directly as pressure in inches of mercury.



The second instrument is used in the framing cameras of Beckman and Whitley. Although the unit is made up of some ninety parts, it is essentially a mirror rotated at high speeds by an air turbine. The unit serves as an intermediary in the camera to relay the image from lenses to shutter device and film.

The turbine rotor is approximately the diameter of a quarter and twice the thickness. With air propulsion the speeds attained with the rotor are comparatively unimpressive; helium, because of its lightness, will drive the rotor at almost twice the speed for the same amount of pressure, and with this gas, angular velocities of up to 18,000 revolutions per second have been attained. To withstand the forces at this speed, the mirror has to be a highly polished and well-balanced alloy-steel piece. The main problems that make higher speeds difficult are the tensile strength of the mirror and the difficulty in finding bearings that will withstand these speeds.

The Buck Instrument Company welcomes interested people to visit their company at Boulder Industrial Park.

Malleable Puts More Muscle in Machinery

In the agricultural equipment field, reputations depend on building products that can take rough treatment . . . and give real value. To do it, agricultural equipment manufacturers rely heavily on Malleable iron castings.

Malleable's excellent ductility and shock resistance mean longer life and fewer problems than obtainable with fabrications. Low start-up cost for small quantities also is vitally important in this competitive industry.

Put more reputation-building quality into your products at less cost with Malleable.

PROBLEM-SOLVING IDEAS are yours free in Data Unit No. 115. For your copy, ask any member of the Malleable Castings Council, or write to Malleable Castings Council, Union Commerce Building, Cleveland 14, Ohio.

MALLEABLE
CASTINGS COUNCIL

The versatility of Malleable Castings is reflected in the variety of ferritic and pearlitic Malleable tractor parts, from the tough, dependable front axle bar to bolsters, lift arms, clamps, clevises, hitches, hinges, foot pedals, transmission planetary carriers and clutch parts.

Silicone Rubber Used as Sealant on Mercury Capsule

A room temperature vulcanizing (RTV) silicone rubber developed by the Silicone Products Department of the General Electric Company, Waterford, New York, has been selected for use on the Project Mercury space capsule that will carry the first American astronaut into space. Silicone rubber is used around rivets and bolts wherever structural material, requiring sealing, overlaps or butts together, to seal the capsule against air leakage. The silicone rubber is applied to conform exactly to the surfaces being sealed. It then cures at room temperature to form a strong silicone rubber that is securely bonded to the metal surfaces. This seal will withstand temperature extremes from minus 70°F. to above 600°F. and is virtually unaffected by ozone and other factors that cause rapid deterioration of ordinary rubbers and sealants.

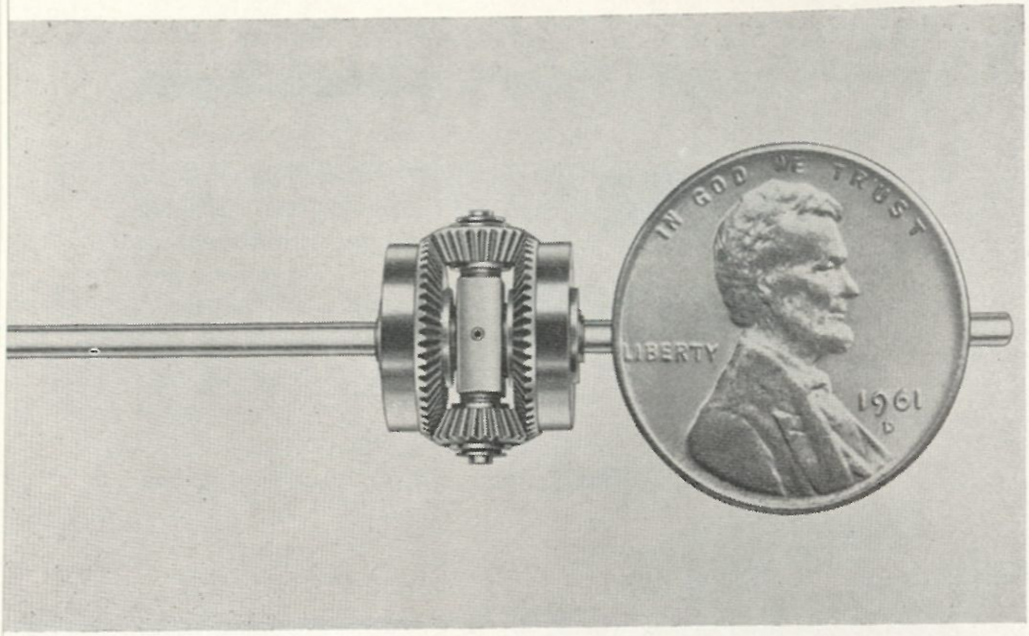
The materials being used are designated RTV-20 and RTV-90. The former is a pourable liquid and the latter a stiff paste. Silicone rubber is already used extensively in conventional forms for seals and gaskets on missiles and high-performance jet aircraft, but the liquid rubbers are greatly expanding the usefulness of the materials.

The silicone rubber-sealed capsule will be carried into orbit over 100 miles above the earth's surface at an orbit velocity of approximately 17,000 miles per hour. As it circles the earth through the vacuum of space, well beyond the earth's protective atmosphere, the capsule will be exposed alternately to the blazing heat of the sun and to extreme cold as it passes through the shadow of the earth. At the proper moment in the orbit path, retrograde rockets will be fired to reduce the speed of the capsule and initiate the re-entry sequence. As the capsule loses altitude, the increasing density of the atmosphere will heat the blunt face of the capsule by friction until it glows a cherry red.

Approximately 15 minutes after the firing of the retrograde rocket the speed of the capsule will have decreased to about 400 miles per hour and a small drag parachute will be deployed to slow the capsule still further. At the proper moment, the main parachute will be automatically opened to allow the capsule and its crewman to settle gently to earth.

THIS TODAY

BILL ROBBINS, (E.E. '63)



Sub-Miniature Precision Differentials

Smaller than a penny the two-spider-gear design was developed by the Instru-Lec Corporation to permit extreme miniaturization for such strategic installations as fire control, navigation, missiles, and aircraft.

Made entirely of stainless steel, each differential employs six miniature ball bearings which conform to ABEC 7 tolerance requirements. Backlash is held to 8 minutes or less, break-away torque to 0.02 ounce-inches, and balance is maintained at all times. Instru-Lec sub-miniature differentials are available with either 0.0779 or 0.0935 inch diameter shafts with overall lengths up to 3 inches. Pitch and number of teeth on end gears can be selected from a wide range. End gears are made from flat blanks that are parallel within 0.0002 inch.

New Laboratory Vacuum System Available from Cenco

A new light weight compact laboratory vacuum system for research laboratories, industrial production and pilot plants has just been announced by Central Scientific.

Ideal for high vacuum depositions of light weight metals, this system features an implosion-proof, 18-inch diameter, aluminum bell jar vacuum chamber with a large plastic window which offers full visibility of the chamber's interior while in operation. A 19-inch diameter pump plate is flanged to the Cenco Three-Way Valve which is connected to a high-speed diffusion pump backed by a Hyvac 14 mechanical pump. The single lever operated Three-Way Valve prevents costly errors due to operation of conventional valves in the wrong sequence. A water-cooled baffle minimizes backstreaming from the diffusion pump. Insulated feed-through electrodes allow high and low voltages from the two built-in power supplies to be introduced into the evacuated bell jar.

The pump stands 71-inches high, it is 30-inches wide, and it is 32-inches deep. Operating on 115 volts A.C. at 30 amperes the system can pump to one micron of mercury in five minutes or less with an ultimate vacuum of 2×10^{-6} mm of Hg. The system's two built-in power supplies provide 500 volts A.C. at 30 ma. and 12 volts A.C. at 100 amps. The cooling system maintains a flow of 0.1 gallon of water per minute.

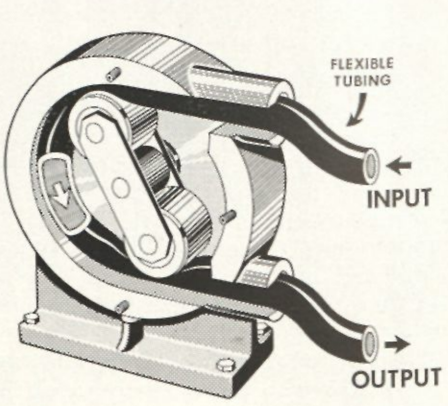
For additional information about the new Laboratory Vacuum System, write to Central Scientific, 1700 Irving Park Road, Chicago 13, Illinois.

Pump With Unusual Design

Hailed as "the pump that never gets wet," the Randolph Pump (made by the Randolph Company, Houston 19, Texas) operates on a principle designed to eliminate all contact of moving parts with the fluid being pumped. Intake and outlet are one continuous flexible tube which passes through the pump body where it is exposed to the squee-gee action of ball-bearing rollers.

By selecting tubing material suitable to the liquid being handled, a wide variety of corrosive, sterile, and abrasive liquids or gases can be pumped without contamination or injury to the pump.

The pump's versatility has resulted in its immediate acceptance by many diverse industries utilizing processes where corrosion, contamination or abrasion were once a problem. Among these industries are firms engaged in the production of beverages, biochemicals, electro-plating, foods, frosted glass, paper pulp, pharmaceuticals, photo - engravings, plastic resins, synthetic fibers, textiles, and TV picture tubes.



A Desk Calculator for Every Student

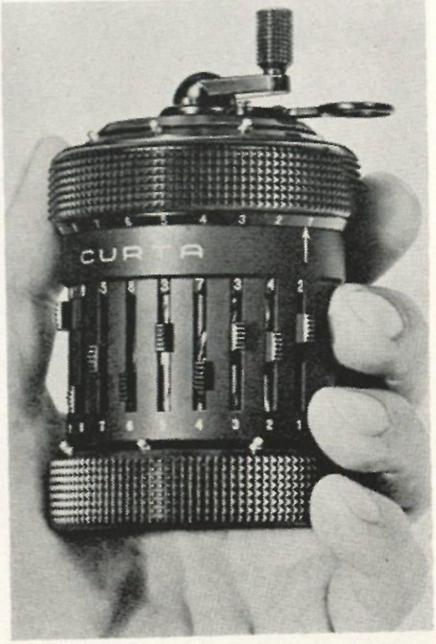
The Type 2 Curta calculator is a new lightweight calculating machine introduced by the Curta Company, 14435 Cohasset Street, Van Nuys, California, for educators, researchers, students, and technicians who require a precise "on-the-spot" answer for every type of mathematical operation.

Combining the accuracy, speed and versatility of a large desk calculator with the portability of a pocket slide rule, the Curta has a capacity of 11 digits on the keyboard, 8 digits on the indicator dial and 15 digits (corresponding to 999 trillion) in the answer dial.

Precision made of stainless steel and high grade anodized aluminum alloys, the cylindrically shaped Curta is only 2 1/16 inches in diameter by 3⅜ inches high (about the size of a fishing reel) and weighs only 12 ounces. Easily held and operated in one hand, the Curta is noiseless in operation, rust and corrosion-proof, and does not require an external power supply.

The main barrel assembly contains the 11 digit horizontal keyboard with color coded setting knobs and movable white decimal markers. A number set on the keyboard remains unaltered until a calculation is completed. A driving axle with the unique step drum and reciprocal cog system passes through the center of the machine and is actuated by a short radius operating handle designed for high speed operation. The knurled carriage contains the revolution counter, result dial and additional decimal markers. A single lever will clear the two dials either simultaneously or individually.

A continuous tens transfer and reversing lever permits short-cut techniques in the basic operations of multiplication, division, addition, subtraction and in multiple operations involving cubes, roots, percentiles, and trigonometric functions. Automatic stops prevent errors in operation or damage from overspeeding in fast operation.



210 Foot Crawler Crane

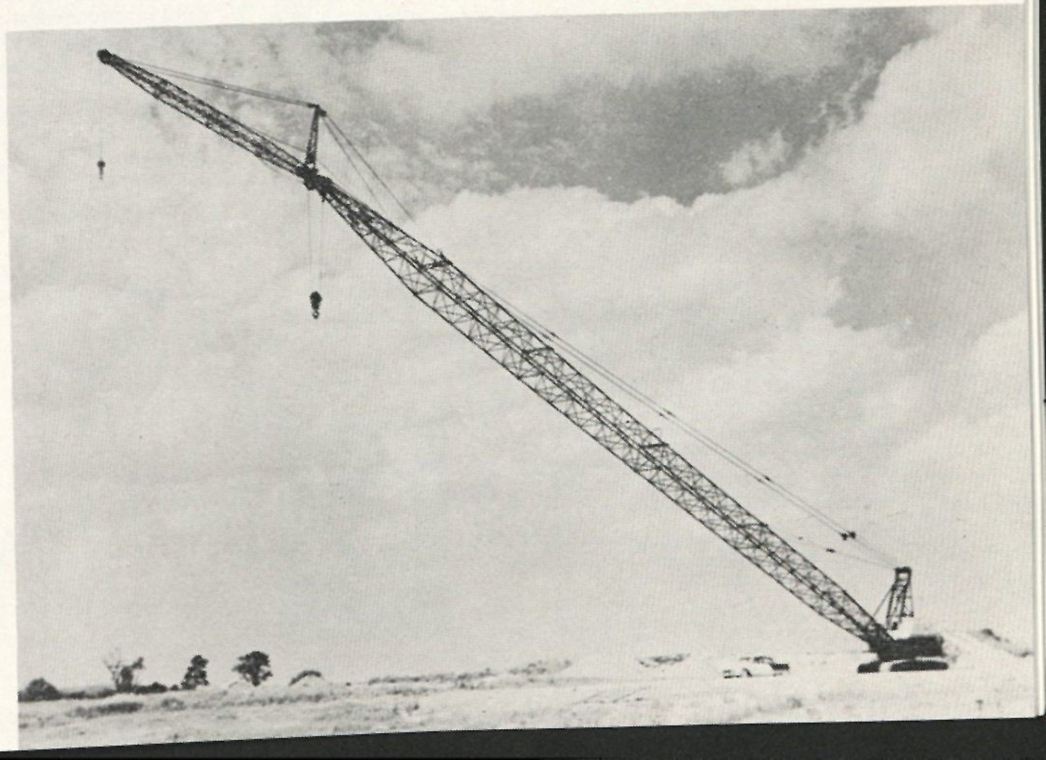
When engineers undertake the design of crawler cranes for extraordinarily high work, one of the first problems they encounter is that of boom weight. That is, how to build a boom, 200 feet or more in length, that is light enough to be supported by a crane platform of reasonable size, but still strong enough to lift a substantial work load.

Built in the conventional manner, that is steel angle lattice construction, a 210 foot boom of the strength required would have more weight than could be counterbalanced by a mobile platform of any practical size. Therefore, to be satisfactory the answer must involve reducing boom weight without sacrificing boom strength. Such an answer can be found by taking advantage of the unique properties possessed by a tube.

The outstanding features of tubular construction are demonstrated again and again by the greatest engineer of them all—Mother Nature. The bones of animals, fish, and birds—hollow by Nature's choice—provide maximum strength for load bearing members while holding weight to a minimum.

In the fabrication of extremely long members such as the crane boom, the structural characteristics of steel tubes provide an advantage in addition to their high strength-low weight property. Their relatively large cross sections provide a boom stability not persent in a comparable boom of angular construction.

The Bucyrus-Erie Company of South Milwaukee, Wisconsin, considered many different materials and construction techniques before deciding on tubular construction. Seamless mechanical tubing of one of the high strength alloy steels was selected as being best suited for the boom construction. To withstand the anticipated stress forces, the material was tested for 70,000 psi minimum yield with 15% minimum elongation in 2". Close to 4000 feet of job-matched tubing went into the largest unit, a 210 foot boom, 40 foot jib combination. The completed crane extends more than twenty stories in the air. The 210 foot tubular boom has a maximum working radius of 170 feet, and the 40 foot tubular jib can be attached to further extend its reach.



PAPER

—FROM ANCIENT ART TO MODERN INDUSTRY

RON COWGILL
(Chem.E. '61)

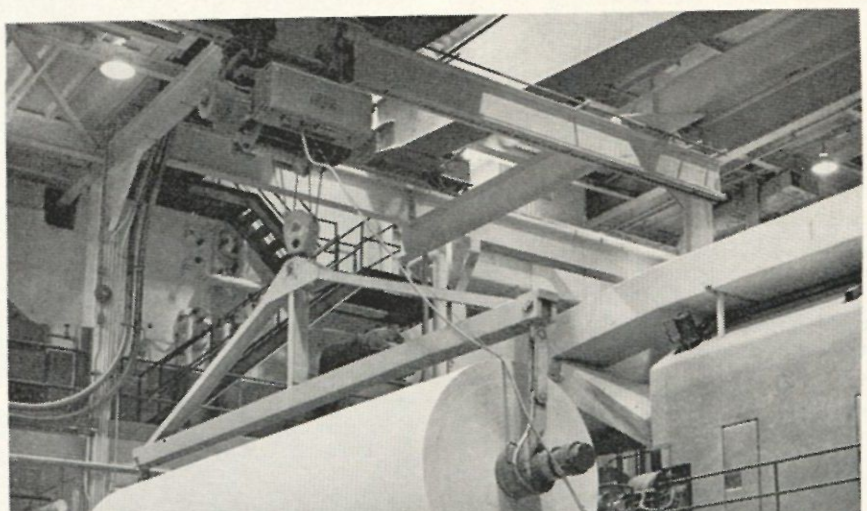
Modern day papermaking has grown from an ancient art to a massive technological industry in just the last one hundred years. The great increase in the use of paper has made advanced research programs necessary in all facets of the paper industry in order to maintain a supply of paper which will be adequate to meet the world's demands.

The Chinese, the first to practice the art of papermaking, did so as long ago as 100 - 200 A.D. The processes which they used were kept secret until 700 A.D. when the Arabs invaded Samarkand. At that time, several Chinese papermakers were captured, and the long kept secret became known.

The process which the Chinese used was simple. They began by grinding bamboo stalks in water to make a pulp. This pulp was then spread on silk screens to allow the water to drain off. After drying in the sunlight, the sheets were peeled off, and the screens were pressed and then finished by rubbing with smooth agate.

Today this art, which moved west from China without any improvement, has become a technologically refined process. Wood is now used instead of the original bamboo stalks. Wood is composed of approximately 50% cellulose, 30% lignin, and 20% carbohydrates. Cellulose is the fibrous material which eventually becomes paper. The fibers are bound by the lignin, a chemical complex similar in action to glue. The first step in papermaking is to prepare the wood for the pulping process by removing the bark. This may be done by one of three methods. In the forest, the felled trees may be hand peeled, or, while standing, a sodium arsenate solution may be injected into the trees causing the bark to fall off. The most common method, however, is to remove the bark in the mill with high pressure water jets. Next, the peeled logs are chewed into fine chips of about ¾ of an inch in length, parallel to the grain of the wood. The chips are then screened and sent to storage bins before being fed to the digesters.

The Kraft or sulfate process is a wood pulping method based on a technique designed to dissolve the lignin and leave behind the separated cellulose fibers. This process can be effectively divided into three stages. First, the chips are cooked with a lime liquor in an autoclave under pressure. The liquor containing the dissolved wood is then processed with a salt cake to recover the valuable



Changing huge rolls of paper on machine at Crown Zellerbach Corporation's St. Helens, Oregon mill. Machine manufactures 9,000 pounds of tissue an hour.

chemicals, after which more lime is added to bring the liquor up to its original composition so that it will be ready for the next cycle.

Three products result from this process. Of primary importance is the wood pulp as it is the main constituent of paper. Secondly, since the process is exothermic, the heat given off can be used to produce steam. This by-product is made when, in the recovery process, the lignin is burned in a smelter to separate it from the lime. The lime sludge, the third product, is reactivated by heating it in a kiln to slake it.

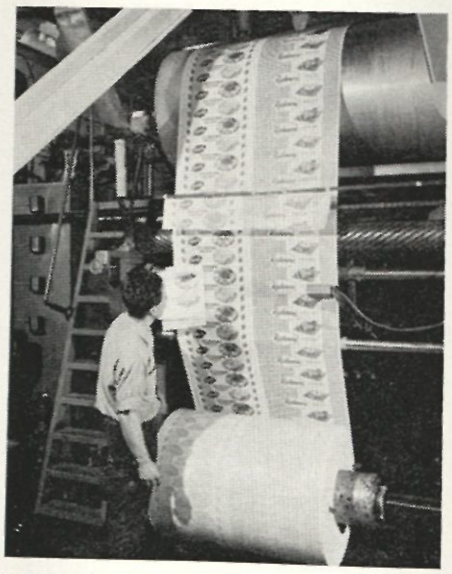
Another process of major importance is the sulfite process. The major difference in the methods used to make the pulp is the difference in chemicals used in the cooking process. The Kraft process uses alkalis while the sulfite process uses an acid in the cooking of the pulp. In the sulfite method, the cooking chemicals are recovered within the cyle, and, in most sulfite mills, the chemicals are sent to by-product plants or used in road surfacing.

The sulfite process has two stages, liquor making and cooking. Liquor is made by burning molten sulphur and absorbing the resulting SO_2 in water. Liquor and chips are then mixed in the digesters and cooked at about 75 pounds of pressure.

The two different processes for making pulp are equally important in the papermaking industry. The Kraft pulp results in a very strong paper, as the German word *kraft* suggests. The sulfite pulp is soft and pliable and results in a finer type of paper. Because both types of paper are in demand, the two processes are equally valuable.

After the pulping process has been completed, the pulp is washed and screened and then fed into a Hollander beater. Beating is the most important part of the papermaking process because the beaters help to fiberize the cellulose which ultimately gives the paper a maximum strength. From the rough beater, the pulp goes through a refiner known as the Jordan Engine. The thickness of the pulp (which determines the quality of the paper) as it comes out of the machine is controlled by two concentric cones.

Before making the final product, many minor ingredients must be added to the pulp. These ingredients affect the final product in various



(TOP):

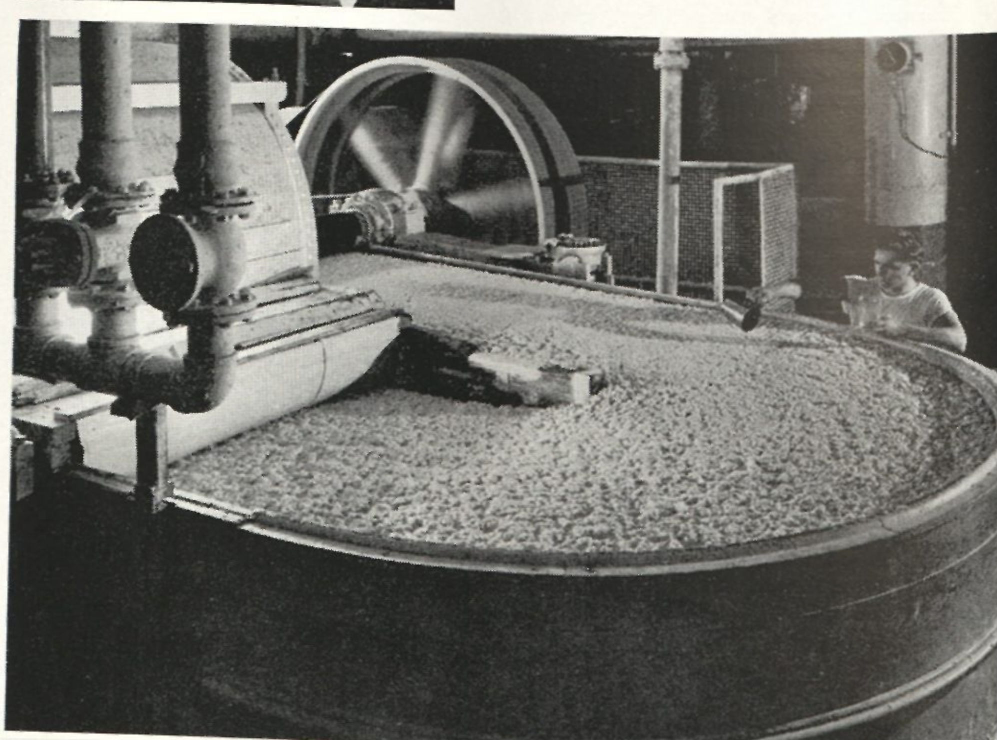
THIS BATTERY OF CENTRICLEANERS AT CROWN ZELLERBACH CORPORATION'S PORT ANGELES, WASHINGTON, PAPER MILL ELIMINATES SPECKS FROM DILUTED PULP BY CENTRIFUGAL SEPARATION.

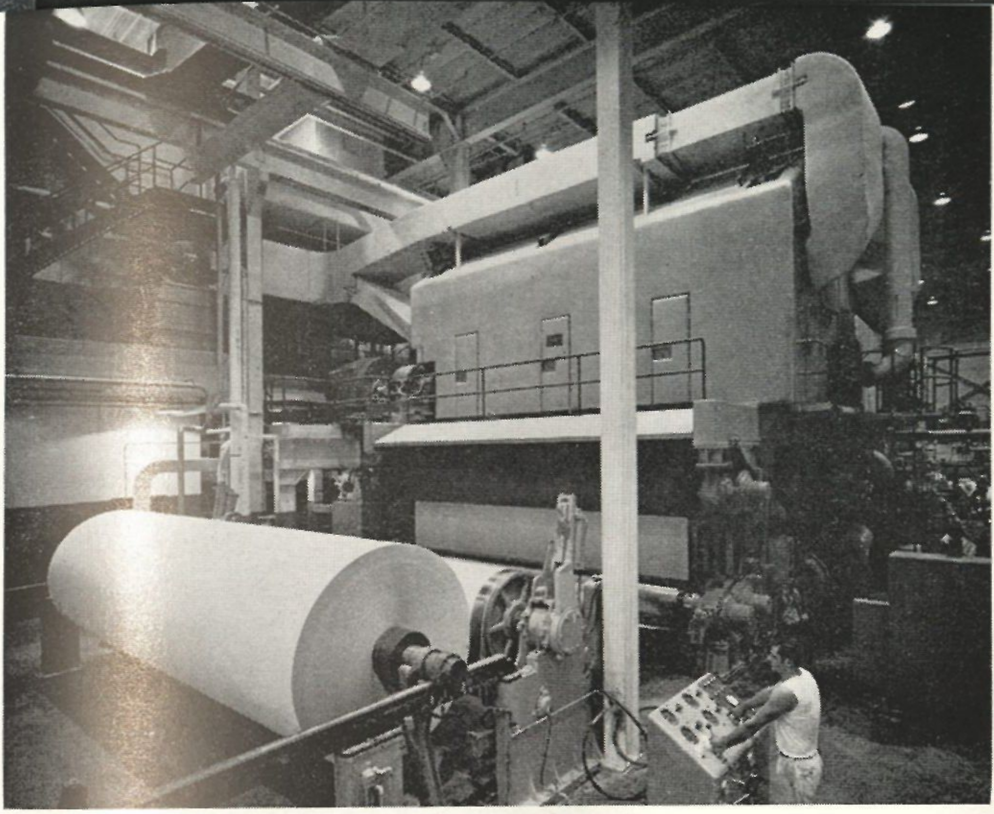
(CENTER):

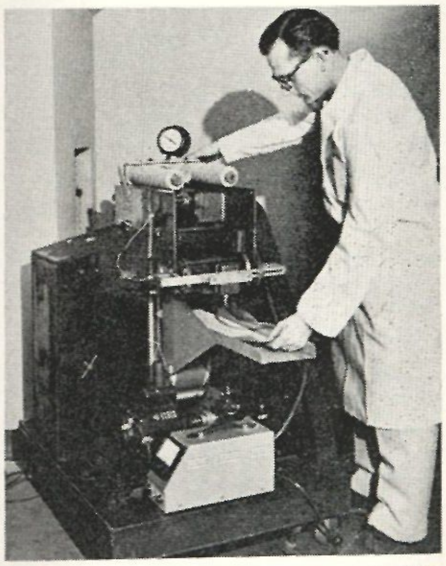
BREAD WRAP IS PRINTED ON THIS 4-COLOR PRINTING MACHINE

(BOTTOM):

PAPER PULP IS MIXED WITH OTHER COMPONENTS OF PAPER IN THIS GIANT BEATER PRIOR TO BEING FABRICATED INTO PAPER.



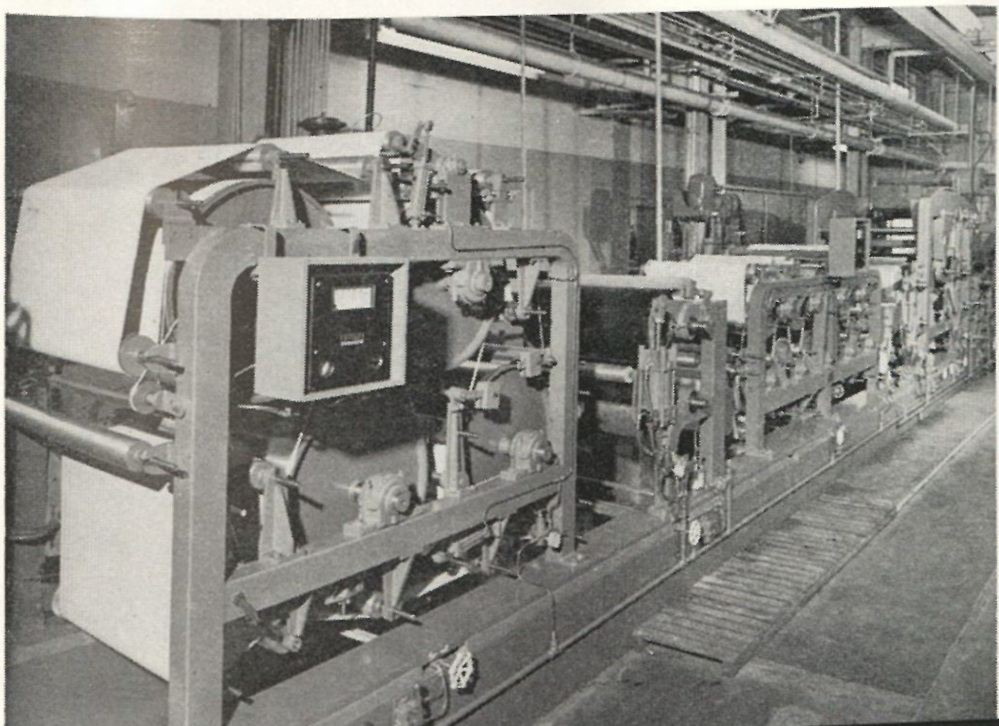




(TOP):
IN BACKGROUND IS WORLD'S LARGEST YANKEE DRYER ON A PAPER MACHINE AT CROWN ZELLERBACH CORPORATION'S ST. HELEN'S, OREGON MILL.

(CENTER):
PRINTABILITY OF NEWSPRINT IS TESTED IN THIS PRESS AT CROWN ZELLERBACH'S CENTRAL RESEARCH DIVISION AT CAMAS, WASHINGTON. THIS IS ONE OF A SERIES OF LABORATORY TESTS WHICH ASSURES QUALITY CONTROL IN NEWSPRINT MANUFACTURING.

(BOTTOM):
THIS EXPERIMENTAL PAPER MACHINE AT CROWN ZELLERBACH'S DEVELOPMENT LABORATORY AT CAMAS, WASHINGTON, CAN DUPLICATE ON A SMALL SCALE THE PAPER MANUFACTURING PROCESS OF THE LARGE PAPER MACHINES, THUS PERMITTING TESTING WITHOUT LOSS OF REGULAR PRODUCTION.



ways. Sizing, which consists essentially of abietic acid (a rosin product), emulsified in water and soda ash, is added to produce paper finish, and alum is added to set the dyes and sizes. Dyes are added to impart color, and alum is used to acidify the pulp. This offets the basicity of the mixture and results in setting the size and dye in the paper pulp. Other additions give different properties to the finished paper. Some of these are clay, talc, $Ti0_2$, Borax, Casein, starch, and diatomaceous earth. These fillers affect the reflective index of the paper and cause variation in paper brightness and printability. This mixture of pulp and ingredients is then fed to the conical blenders, and, after being mixed by this machine, the pulp mixture is ready for papermaking.

Most modern papers are made on the high speed Fourdrinier paper machine. This machine is one of the largest continuous process machines in industry, and its construction is one of the marvels of technology. It consists of two divisions, a "wet" end and a "dry" end. On the wet end, the stuff box receives the pulp mixture and distributes its load to the head box. A uniform fiber-suspension is obtained and maintained in the head box. From this the paper pulp flows onto a moving belt through a slot known as the "slice" which determines the paper thickness. At that point, the removal of water is immediately begun, and the paper progresses through a series of roles, felts, and presses before being collected on the final role.

Of course, the use of technology doesn't end with this raw paper product. Machines designed to coat the paper for various uses are next in line, and, in some instances, the paper goes directly from here into a printing press.

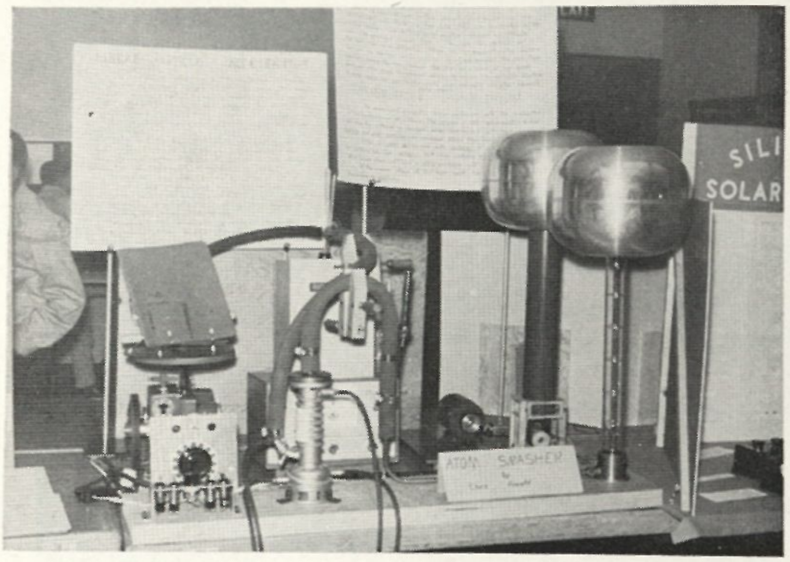
Predictions indicate that paper usage will double in the foreseeable future. The amount of paper to be produced in the future will be determined and limited by educated men. As long as we continue to do research and to build better machines, man will be provided with all of his paper needs.

ADVERTISERS' INDEX


1961-62
CONSTRUCTION PLANS
1. INVESTMENT $80,000,000
2. EXPENSE $32,000,00
3. MODERNIZATION $18,00

ENGINE PREP

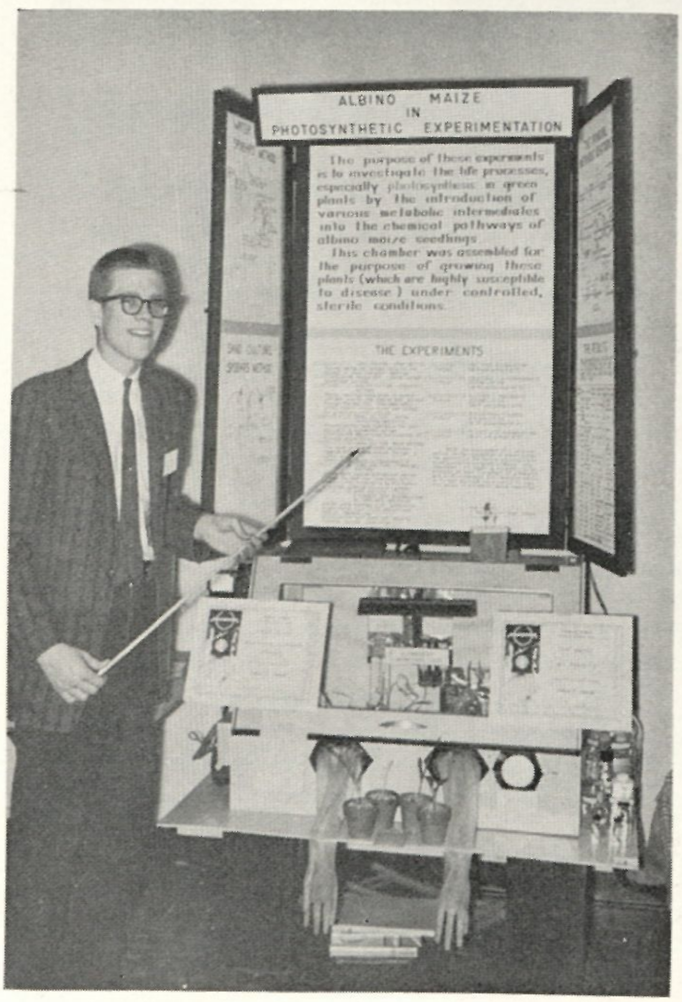
SUE WILLIAMSON

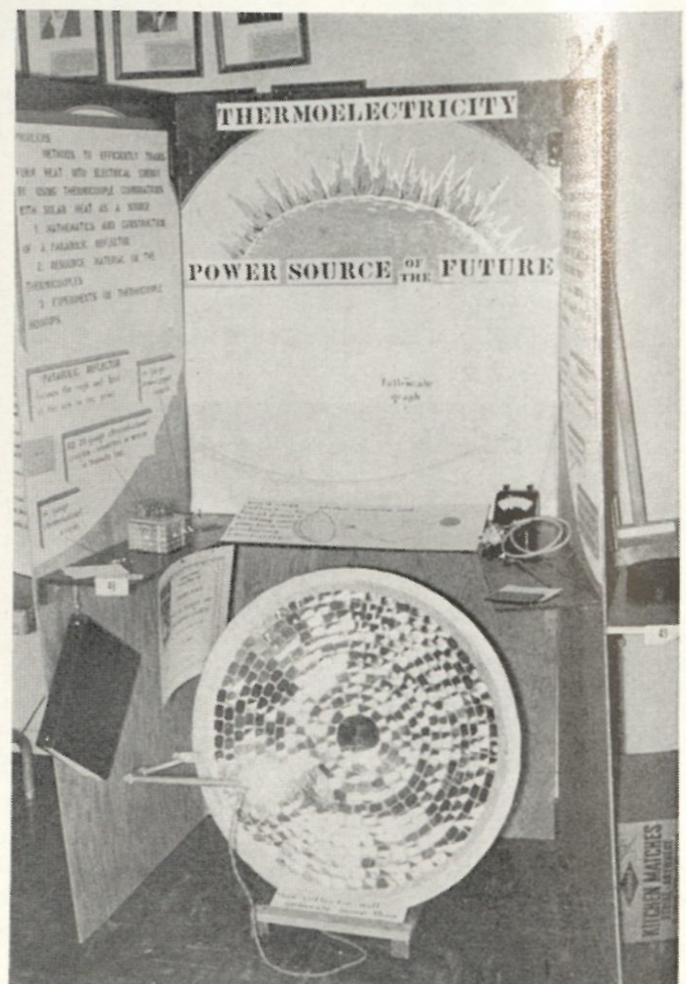


(LEFT) ATOM SMASHER
BY CHRIS FINNOFF

(LOWER LEFT) GRAND PRIZE WINNER
ROBERT COLWELL

(LOWER RIGHT) JOHN HUDSON'S
FIRST PRIZE WINNING
THERMOELECTRICITY EXHIBIT





SCIENCE FAIR

The sixth annual Colorado-Wyoming Science Fair was held April 14 and 15, in Boulder, Colorado. The 147 exhibits were divided into two groups; the senior high projects shown at the Bureau of Standards and the junior high displays at Base Line Junior High School.

The University Memorial Center was the scene of the Saturday luncheon at which the winners were announced. Biological projects took first and second prizes. Robert Colwell, a senior at George Washington High School in Denver, won his first prize with "Albino Maize in Photosynthetic Experimentation." Kenneth L. Weaver's exhibit entitled "The Effects of Carnotite Radiation on the Reproduction and Mortality Rates of Daphnia Magna" won his second prize award. He is a sophomore at Greeley High School. Both winners will attend the National Science Fair to be held May 10-13, in Kansas City, Missouri. John Hudson, a sophomore from Branson High, Branson, Colorado, was chosen alternate. His project was "The Centrifugal Action on Solidifying Material and Lunar Ring Walls." John, incidentally, was the top junior high winner last year with an entirely different project.

In the junior high division, Alan Dudley from Skinner Junior High in Denver won first prize for his "Radioactivity" exhibit. Second prize went to Mike Higgins from Lakewood for his mathematical "Magic Squares."

Prizes were also awarded in the three main areas.

Biological Sciences, Senior High: first, Robert Colwell; second, Kenneth Weaver; third, Edward Brady, a sophomore from Kemmerer High, Kemmerer, Wyoming, with "An Explanation of Muscle Contraction through ATP"; honorable mention, William Lake, sophomore at Machebeuf High, Denver, with "The Respirometer."

Mathematics, Senior High: first, Judith Rice, sophomore at Littleton High, with "The Hitchcock Transportation Problem"; second, Barbara Jones, senior at Cherry Creek High, Littleton, with "Theory of Probability"; third, William Orr, junior at Cherry Creek High, with "Function of a Complex Variable"; honorable mention, Steve Kinney, senior at Ouray High, Ouray, with "Math Magic."

Physical Sciences and Engineering, Senior High: first, John Hudson; second, Ken Ogan from Ault High, Ault, Colorado, with "Thermoelectricity—A Power Source for the Future"; third, Elizabeth DeVore, sophomore at University High, Laramie, Wyoming, with "Chemical Properties of Crystals"; honorable mention, Carl Hanson, senior at Cheyenne Mountain High, Colorado Springs, with "Determining Possibilities of Supplementing Visual and Auditory Senses with the Tactile Sense."

Biological Science, Junior High: first, Patrice Miles, Smiley Junior High, Denver, with "Mystery of Heredity"; second, Scott Dyer, Horace Mann Junior High, Colorado Springs, with "Cobalt Chicks, Irradiation of the Chick Embryo to Observe the Internal Effects, Mainly on the Heart"; third, Dallas Sandy, Grand Junction Junior High, with "Tyrosinase as a Precursor of Melanin; honorable mention, Karen Higgins, Lakewood Junior High, with "Lichenology."

Mathematics, Junior High: first, Mike Higgins; second, Dustan Osborn, Cherry Creek High School, with "Measuring Irregular - Shaped Areas"; third, Wayman Walker, College High, Greeley, with "Completely Tetrahedral Sextuples"; honorable mention, Stephen Flax, Hill Junior High, Denver, with "Mind Reading Computer."

Physical Sciences and Engineering, Junior High: first, Alan Dudley; second, Virginia Freeman, East Junior High, Colorado Springs, with "Experimenting with Vacuum"; third, Dennis Schatz, Hill Junior High, Denver, with "Micro-Meteorites Around the World"; honorable mention, Luke Danielson, Centennial Junior High, Boulder, with "Galileo's Pendulum."

Fifty-one judges from throughout Colorado and Wyoming had the difficult task of determining these winners. One of the judges, Harold Martin who works for the Dow Chemical Company at Rocky Flats, was himself a top winner in the 1956 Science Fair.

Approximately four thousand people saw the outstanding projects of hard working students. Many of the students are already beginning work on an exhibit for next year. Tentative dates for the 1962 Science Fair are April 13 and 14.

Engineering Physics

Throughout the world engineering physicists are in great demand. Finding employment in industries concerned with atomic power, communications, and other such fields, the young physicist has overwhelming opportunities.

At the University of Colorado the curriculum for a degree in engineering physics stresses broad training in both the theoretical and practical aspects of mechanics, heat, light, electricity, and atomic and nuclear physics. Of course, a sound basis in mathematics is essential.

The engineering physicist is interested in applying his knowledge of physics to practical uses. His training should give him a basic background for work in various fields.

The high school student who wishes to go into this branch of engineering should have a good aptitude for mathematics and science. He must want to understand the how and why of many objects and forces. To the student with desire and determination, engineering physics will prove to be a challenging and rewarding career filled with unlimited possibilities.

Aeronautical Engineering

Students interested in airplanes, missiles, and all forms of space-craft should look into the rapidly developing field of aeronautical engineering. This new science which started with man's desire to fly has now grown into a field whose industries employ thousands of men and women in the design, development, and manufacture of all air and space vehicles.

Aeronautical engineers are in demand both in private industries and government agencies. The choice of specialties is numerous, and the opportunities are infinite.

The high school student should begin building a good background in mathematics and science. He must be able to work well with others as he will definitely become a part of a team. A creative imagination and a strong determination are likewise essential.

A student at the University of Colorado may choose a major in aerodynamics, structures, or propulsion. He may also study the many fundamentals of space flight.

Aeronautical engineering is a worthwhile career in which even the sky is not a limit.

ALUMNEWS

Compiled by
THERESA STEPHEN, Ch.E. '64

In this last article of Alumni news, I am presenting a feature story about an unusual educational project of one of CU's alumni. The acknowledgment of this project was revealed to me when DAVID M. BOYD, JR., B.S. (Ch.E.) 1941, and Degree of Chemical Engineer (1950), visited the University prior to spring vacation, while on a trip to the Colorado School of Mines to speak on process control.

Mr. Boyd, chief instrument engineer for Universal Oil Products Company of Chicago, represented the International Federation of Automatic Control in Russia last June as vice-chairman of the American delegation. Previously in 1956, he was sent to Heidelberg, Germany, on a lecturing assignment at the University of Heidelberg. It was there that he learned of the Russian science education from a Russian scientist lecturing there. Learning from Russian propaganda that Russia's science edcuation completely surpassed that of the United States, Boyd desired to visit and investigate the science education in this country. He learned from Professor Dunning of Columbia University that Russian engineering students are paid to go to school and that upon graduation receive almost five times that of a Russian truck driver. In the United States, the average engineer upon graduation receives nearly the same pay and many times only half as much as that of the U.S. truck driver.

If this country was lacking in science education, what was causing the lag and with what measures could this lag be overcome? Seeking a solution to this question, Boyd visited the Hinsdale High School in Illinois, but he found himself very impressed with the science program. After conversing with some of the members of a ham radio club at the school, and explaining the fundamentals of digital computer circuits and Boolean algebra, he aroused the interest of the students in digital computers and the binary counting principles. Then with some electronic equipment donated by Boyd, they began building their own computer. These young scientists of Hinsdale High School and Junior High School ranged in ages from 13 to 17. "Operation Snowball" grew with donations and publicity.

Working fervently until after midnight many nights in the basement of David Boyd, the youths constructed a 15-word capacity computer with a word length of 10 bits. Relays and a flexowriter were donated by Panellit, Inc. for the adding and subtracting units, shift registers, and memory cells.

"Operation Snowball" revolutionized when *Control Engineering* procured a donation of a $10,000 magnetic drum with 50 heads from Bryant Computer Products. This was the beginning of the transistorized digital computer. Diodes, transistors, condensors, and other component parts were donated by many computer part suppliers. After more than two years of work and remarkable progress, Bryant Computer Products offered to put 250 heads on the magnetic drum to give a 8,000-word capacity. The result after four years was an 8,000-word transistorized digital computer with a possibility of 128 commands. Mr. Boyd laid down the theory and principles for the project, but the boys carried out the actual construction.

Mr. Boyd feels that with attention, inspiration, and assistance to our youth the science education of the United States can compete with the tough educational system of Russia.

As an added note of interest about Boyd, he is an expert photographer, a sports car enthusiast who owns a Mercedes and has won a number of cups and ribbons in rallies, and a grower of orchids.

* * *

ORAL L. MOORE, B.S. (C.E.) 1948, has recently been named the General Manager and Chief Engineer for the Hetch Hetchy Project, Utilities Engineering Bureau and Bureau of Light, Heat, and Power in San Francisco. This new position entails responsibility for all engineering and construction projects of San Francisco International Airport, the Municipal Railway and Hetch Hetchy. Moore has worked with the public utility program in the Golden Gate city for 12 years.

* * *

KENT TOSHIO YORITOMO, B.S. (E. Phys.) 1951, was honored for his work at the Geodesy, Intelligence, Mapping Research & Development Agency in Fort Belvoir, Virginia. Besides receiving a certificate for superior performance, Yoritomo was also given $250.

* * *

CARL WULSTEN CONNORS, B.S. (C. E.) 1924, is vice president-general manager of the Mountain States Telegraph and Telephone Company in El Paso. Connors served as president of the annual Sun Carnival in 1960-1961.

* * *

RICHARD M. VOILS, JR., B.S. (M.E.) 1943, was named Engineer of the Month by the Southern California Meter Association in its November, 1960 issue of the *Engineer of Southern California*. He is with the Mobil Oil Co. (General Petroleum).

* * *

MERRIT OLDAKER, B.S. (Aero. E.) 1948, has been named liaison representative for the missiles and space division of Lockheed Aircraft Corporation in Washington, D. C. He has been with Lockheed for nine years.

* * *

An electronics engineer with the Bureau of Standards in the cryogenic laboratory, JOHN RUSSELL PURCELL, JR., B.S. (E.E.) 1956, was speaker at the recent cryogenic colloquium held in Boulder.

MR. BOYD (FAR RIGHT) DISCUSSING THE COMPUTOR WITH A GROUP OF STUDENTS AND FACULTY

For Your Library

BOB LOUTHAN, (E.E. '61)

From Dry Plates to Ektachrome Film

By Dr. C. E. K. Mees; Ziff-Davis Publisher Photo Research History; Rochester, N. Y., 1961.

A history of photographic research written by the late Dr. C. E. Kenneth Mees, a pioneer in the industrial application of research, has been published by Ziff-Davis Publishing Co.

Entitled *From Dry Plates to Ektachrome Film — A Story of Photographic Research*, the new book is written for the advanced amateur and the photographic scientist. It provides a wealth of material about "the theory behind the photograph."

The book has more than 150 illustrations and is documented from Dr. Nees' long experience as director of Kodak Research Laboratories in Rochester, N. Y. The laboratories, which he founded in 1912, were responsible for such photographic innovations as amateur motion pictures and new color photographic processes. Known world-wide for his work in photographic science and as an authority on complex color photography processes, Dr. Mees guided Kodak research for nearly 44 years. From the beginning of his early experimentation in photography more than a half a century ago, Dr. Mees held to his aim of adding to knowledge of the scientific theory of photography. A milestone of this course came in 1942, with the publication of his book, "The Theory of the Photographic Process."

In the new book are chapters on the early history of photography and on first applications of science to photography. Accounts of research on photographic image structure, film sensitivity, developers, sensitizing dyes and gelatin, illustrate the scientific progress that led to modern photography. The author also tells of the long search that resulted in cellulose acetate for safety-base film.

Other sections of the book are devoted to the history of amateur and professional movies, sound recording on film, color photography, and X-ray research. Other chapters deal with photography and the graphic arts, photographic materials for scientific use, and the role of Kodak Research Laboratories after World War II.

A chapter on non-photographic research problems deals with subjects such as camouflage, measurements of visibility, synthetic organic chemicals, and the manufacture of optical glass and high-vacuum equipment.

Handbook of Instrumentation and Controls

A Practical Manual for the Mechanical Services Covering Steam Plants, Power Plants, Heating Systems, Air-conditioning Systems, Ventilation Systems, Diesel Plants, Refrigeration, and Water Treatment. By Howard P. Kallen, 692 pp., 550 illustrations. McGraw-Hill. $15.00.

Planned to help the reader determine how to best select and effectively apply instruments and control systems for mechanical services in commercial, institutional, and industrial buildings, this newly published handbook provides a wide range of authoritative and quantitative data. The book extends from basic facts on instruments to thorough descriptions of complete control systems; it should serve as a guide presenting important information needed to procure, specify or design equipment.

In treating instrumentation for pressure, temperature, flow, liquid level, pH and conductivity, combustion, and boiler controls, the needs of the engineer who designs and develops instruments, as well as the application engineer, were kept in mind. Similar consideration for the practical needs of engineers, technicians, and others is extended in the coverage of turbine-generators, heating systems, air-conditioning systems, refrigeration systems, diesel engines, and other controls.

Lengthy, complicated discussions are omitted in favor of many quick-reference data. Numerous clear illustrations and tables, charts, and graphs are used to convey technical aspects of instrumentation. Of particular interest is the presentation of many control systems that are completely illustrated to demonstrate modern practice in the field. Typical practical applications of all controls are described.

Specialized phases, including boiler and combustion controls, boiler flame-failure safeguards, and the fundamentals of instrument system design are covered. Also the book includes newer developments such as control systems for high-pressure steam power plants, and controls for large central air-conditioning systems found in office buildings, hospitals, schools, and other commercial and institutional buildings.

Howard P. Kallan is a partner in Kallen & Lemelson, Consulting Engineers, a firm that specializes in the design of mechanical services systems for commercial, industrial, and institutional buildings. Formerly, he was Chief Mechanical Engineer for Frederic R. Harris, Consulting Engineers, and an Associate Editor of *Power*. He is a member of the American Society of Mechanical Engineers and the Instrument Society of America.

Advances in Cryogenic Engineering

Edited by K. D. Timmerhaus. Volume 6: 652 pp., illustrated, $15.00. Plenum Press, Inc.

Cryogenics, the science dealing with low-temperature phenomena, is explored further in *Advances in Cryogenic Engineering*, Volume 6, the latest addition to this important series. Volume 6 contains the Proceedings of the 1960 Cryogenic Engineering Conference, held by the University of Colorado and the National Bureau of Standards.

The most significant aspect of cryogenics lies in its ultramodern applications--notably in masers and in new types of computers which have diodes and transistors operating in the very low Kelvin ranges, and perhaps even more important today, in astronautics. These aspects and many more are treated thoroughly in the six volumes of this series.

Advances in Cryogenic Engineering, Volume 6, contains 65 technical papers by leading scientists in the cryogenic engineering field. The reports are divided into the following general sections: Space Technology, Applications, Superconductivity, Processes, Transfer Phenonmena, Equipment, Physical Equilibria and Related Properties, Heat Transfer and Thermometry, and Mechanical Properties.

This continuing series of volumes enables every scientist and technician interested in cryogenics to keep fully informed of new developments in the field.

Changes are wrought all the time. So we thought you might like to see . . . .

The New Engineering Courses

Object of Courses

The object of the engineering courses at the University of Colorado is to train and develop men by means of engineering. A thorough and systematic training in the science of engineering is given, leaving skill in the trade of engineering to be gained after graduation. Emphasis is placed upon theoretical considerations for it is realized that practical work can be intelligently understood and improved methods advanced only after a thorough knowledge of the principles involved has been acquired. The best possible training is given the student so that he can attack the problems which will confront him with confidence and feel that his methods are sound. Enough of the trade of engineering is taught so that the science of engineering can be fully understood and to enable the graduate to immediately assume his place in the engineering world and be of value to his employers from the start. One might devote most of his four years in college to becoming proficient at the lathe or in manipulating the transit but after graduation he would qualify only as a machinist or a surveyor and not as an engineer. In brief, the aim of the College of Engineering is to turn out engineers with high ideals who are well equipped for practical work and who will continue to study to keep pace with the rapid progress of the profession of engineering.

Outline of Courses

Every minute of the student's time is considered valuable so none can be wasted in repetition of the same work in different courses or in studying courses which are not strictly abreast with the times. This requires frequent changes in the work taught and a widening of its scope. The courses at the University of Colorado have been changed considerably this year. A system of options has been adopted which enables a student to prepare for the line of work in which he is particularly interested, but giving the essential courses to all, so that there will not be danger of over-specialization. The four major branches of engineering, i.e., Civil, Electrical, Mechanical and Chemical, are subdivided as shown in the accompaning outline:

I. Civil Engineering

1. Structural Engineering.
2. Railway Civil Engineering.
3. Irrigation and Highway Engineering.

II. Electrical Engineering

1. Power and Lighting Engineering.
2. Railway Electrical Engineering.

III. Mechanical Engineering

1. General Mechanical Engineering.
2. Railway Mechanical Engineering.

IV. Chemical Engineering

It will be seen that a student taking the Civil Engineering course can specialize in Structural Engineering, Railway Civil Engineering or Irrigation and Highway Engineering, and that there are corresponding options in the other courses. The choice between the four major courses is made at the beginning of the second year but the choice between the sub-divisions of the major courses is not made until the middle of the third year for Civil and Mechanical Engineering and the beginning of the last year for Electric Engineering. The character of work taken each year will now be explained.

The Freshman Year

All Courses. Throughout the first year all courses are the same so that a choice need not be made until a student has had a year at college to consider the problem. During this year work is given in mathematics, chemistry, rhetoric, and drawing.

The Sophomore Year

At the beginning the second year one of the four major engineering courses must be chosen for it is during this year that elementary work in strictly engineering subjects is given.

All Courses. During this year all students continue their study of mathematics and are given courses in physics, mechanics, and the materials used in engineering construction.

Civil Engineering. Civil Engineering students begin the study of surveying, railway location, roads and pavements, and timber structures.

Electrical and Mechanical Engineering. Electrical and Mechanical Engineering students take shop work, and elementary courses in the design and construction of machines.

Chemical Engineering. Students in Chemical Engineering are given advanced work in chemistry by taking qualitative and quantiative analysis.

Junior Year

All Courses. All students continue their study of mechanics during their third year, take up the study of steam engines and boilers, and are given a thorough course in technical writing.

Civil Engineering. Students in Civil Engineering are given work in geology, railroad location, stresses in structures, the methods of construction of buildings and bridges and make a study of the flow of water in pipes and channels. During the second half of the junior year, those who specialize in Structural Engineering are given courses in the history of architecture, methods and materials of architectural construction, and the heating and ventilation of buildings. Those who specialize in Railway Civil Engineering are given work in railway terminals and maintenance, while those who specialize in Irrigation and Highway Engineering take up the location and construction of canals, reservoirs and highways.

Electrical Engineering. All electrical engineering students make a study of the types, theory, testing and design of electrical machinery; the relation between heat and work; and differential equations.

Mechanical Engineering. The mechanical engineering students are given courses in machine design, machine shop, electrical machinery, the flow of water, and relation between heat and work. Those who take General Mechanical Engineering make a study of the heating and ventilation of buildings and those who specialize in Railway Engineering make a study of locomotives and air brakes.

Chemical Engineering. During the third year all chemical engineering students are given courses in physical chemistry, one analysis, machine design, electrical machinery, and the relation between heat and work.

Senior Year

ALL COURSES. The senior year is devoted to advanced work in the special lines of engineering. All senior students make a study of business law, contracts, and specifications. In each course one hour a week is devoted to the study of various engineering projects, the history of engineering, and current engineering literature. Exceptional students are permitted to carry on original investigation along lines in which they are particularly interested.

CIVIL ENGINEERING. All Civil Engineering students are given a thorough training in the design and construction of bridges and buildings of steel and reinforced concrete, and of various concrete and masonry structures, such as arches, walls and dams. Advanced courses are given in the calculation of stresses in structures. Courses are given in water supply and sewage disposal systems for cities. Civil Engineering students who specialize in Structural Engineering continue the study of mechanics and take up the design and construction of office buildings, mill structures and mine structures. Those who specialize in Railway Civil Engineering continue their study of railway problems, taking up railway operation and railway structures. In irrigation and Highway Engineering more time is devoted to structures employed in the construction of highway and irrigation projects, and to the problems in design and maintenance which confront highway and irrigation engineers.

ELECTRICAL ENGINEERING. All Electrical Engineering students continue the study of alternating current machinery, steam engines and illumination. Problems in the transmission and distribution of electrical energy are given sonsiderable study. Courses are given in surveying and in the design of structures. Those students who specialize in Power and Lighting Engineering make a study of the installation and operation of railway system, the location and design of electric power plants and the installation and operation of telephone systems. Students who elect Railway Electrical Engineering devote considerabel time to the design of electric railway equipment and the problems of installation of electric power on railways.

MECHANICAL ENGINEERING. All Mechanical Engineering students continue the study of steam engines and steam turbines. Courses are given in the theory, construction and operation of automobiles, gas engines, and hydraulic machinery. The design, construction and management of industrial plants are considered. A course is given in compressed air and its application to pneumatic machinery. Those who elect the General Mechanical Engineering course are given work in power plant design and study refrigerating machinery. If Railway Mechanical Engineering is elected courses are taken in the operation of railways and the design of locomotive shops and terminals.

CHEMICAL ENGINEERING. All Chemical Engineering students study the design of chemical plans considering the chemical, mechanical and structural features. Advanced work is given in organic and industrial chemistry, geology and steam engines.

Summary

This description of the courses shows that a thorough training is available at the University of Colorado, in nearly every branch of engineering. The teaching staff ranks with the best in the country and the laboratory facilities are excellent. A very large percentage of graduates are practicing engineers and are holding positions of responsibility. There has been such a demand for graduates of the College of Engineering that the University has been able to locate every man as soon as his course is completed.

Now before you panic, realize that this curriculum is 45 years old. The above is reprinted from the May, 1916 issue of *The Colorado Engineers' Magazine,* the predecessor of the *Engineer.* So realize that things haven't changed too much except for scope.—Ed.

Cryogenic Thermometry

(Continued from page 16)

References

1. R. L. Weber, Heat and Temperature Measurement, Prentice Hall, Inc., New York (1950) pp. 263-266; J. F. Lee and F. W. Sears, Thermodynamics, Addison-Wesley Publishing Co., Cambridge, Massachusetts (1955) pp. 18-20.
2. M. W. Zemansky, Heat and Thermodynamics, 4th ed., McGraw-Hill Book Co., Inc., New York (1957) p. 16 .
3. H. F. Stimson, J. Res. NBS 42, 209 (1949); H. F. Stimson RP 1962; C. T. Linder, Research Report R-94433-2-A, Westinghouse Research Laboratories, East Pittsburgh, Pa. (Feb. 2, 1950); J. A. Hall in Temperature, Its Measurement and Control in Science and Industry, Vol. 2, Reinhold Publishing Corp., New York (1955) p. 115.
4. H. van Dijk in Problems of Low Temperature Physics and Thermodynamics, Pergamon Press, London, England (1959) p. 103; G. C. Lowenthal, W. R. G. Kemp, and A. F. A. Harper in Problems of Low Temperature Physics and Thermodynamics, Pergamon Press, London, England (1959) p. 107; R. J. Corruccini, Rev. Sci. Instr. 31, No. 6, 637 (1960).
5. H. J. Hoge and F. G. Brickwedde, J. Res. NBS 22, 351-373 (1949); RP 1188.
6. R. B. Scott in Temperature, Its Measurement and Control in Science and Industry, Vol. 2, Reinhold Publishing Corp., New York (1955) p. 179.
7. H. van Dijk in Progress in Cryogenics, Vol. 2, K. Mendelssohn, ed., Academic Press, Inc., New York (1960) p. 123; H. van Dijk and M. Duriex, Physica 24, 920 (1958).
8. G. K. White, Experimental Techniques in Low Temperature Physics, Oxford University Press, Oxford, England (1959) p. 90.
9. A Compendium of the Properties of Materials at Low Temperature, Phase I, V. J. Johnson, ed. WADD Tech. Rept. 60-56, Part I (October 1960).
10. G. K. White, Experimental Techniques in Low Temperature Physics, Oxford University Press, Oxford, England (1959) pp. 93-94.
11. J. A. Beattie in Temperature, Its Measurement and Control in Science and Industry, Vol 2, Reinhold Publishing Corp., New York (1955), p. 63.
12. R. B. Scott in Proceedings of the 6th ISA National Flight Test Instrumentation Symposium, San Diego, California (May 2-5, 1960).
13. R. B. Scott, Cryogenic Engineering, D. Van Nostrand Company, Inc., Princeton, New Jersey, (1959), p. 177.
14. G. K. White, Experimental Techniques in Low Temperature Physics, Oxford University Press, Oxford, England (1959), p. 109.
15. C. H. Meyers, J. Res. NBS 9, 807 (1932); RP 508.
16. G. K. White and S. B. Woods, Rev. Sci. Instr.28, 638 (1957).
17. J. G. Daunt in Temperature, Its Measurement and Control in Science and Industry, Vol. 2, Reinhold Publishing Corp., New York (1955) p. 331.
18. C. R. Barber in Progress in Cryogenics, Vol. 2, K. Mendelssohn, ed., Academic Press, Inc., New York (1960) p. 153.
19. S. A. Friedberg in Temperature, Its Measurement and Control in Science and Industry, Vol. 2, Reinhold Publishing Corp., New York (1955) p. 366.
20. J. E. Kunzler, T. H. Geballe, and G. W. Hull, Rev. Sci. Instr. 28, 96 (1957).
21. J. R. Clement and E. H. Quinell, Rev. Sci. Instr. 23, 213 (1952).
22. M. H. Edlow and H. H. Plumb in Advances in Cryogenic Engineering, Vol. 6, K. D. Timmerhaus, ed., Plenum Press, Inc., New York (1961) p. 542.
23. R. L. Powell, M. D. Bunch, and L. P. Caywood in Advances in Cryogenic Engineering, Vol. 6, K. D. Timmerhaus, ed., Plenum Press, Inc., New York (1961) p. 537.
24. R. B. Scott, Cryogenic Engineering, D. Van Nostrand Company, Inc., Princeton, New Jersey (1959) p. 123.
25. F. Din and A. H. Cockett, Low-Temperature Techniques, George Newnes Ltd., London, England (1960) p. 71.
26. D. De Klerk in Encyclopedia of Physics, Vol. XV, S. Flügge, ed., Springer-Verlag, Berlin, Germany (1956) p. 143; D. De Klerk in Temperature, Its Measurement and Control in Science and Industry, Vol. 2, Reinhold Publishing Corp., New York (1955) p. 251.
27. N. Kurti, Physics Today 13, No. 10, 26 (Oct. 1960).

Meet The Staff

(Continued from page 37)

only comment on marriage is that "Marriage is the best thing for people with children." His hobbies are fishing, hiking, photography, and the study of women, weapons, and warfare. He modestly admits (with a straight face) that he is shy, quiet, bashful, well-behaved, and afraid of females, and he hopes someday to overcome these personal obstacles.

PATSY MURNANE

Patsy Murnane, office manager of the *Colorado Engineer,* is a sophomore in Chemical Engineering. Finally graduating from Salida High School, Salida, Colorado, she decided to try her luck at the University of Colorado. To prevent boredom she has become secretary of AIChE and High School Convocation Chairman of Engineer's Days. She is also interested in other things such as music, most sports and the usual pastime, males.

JEAN ANN CLARK

Jean Ann, or DOC as she is sometimes known, is the editor's private secretary. In truth she is also his wife, for on Valentine's Day (romantic, isn't it?) they tied the well-known knot. Doc is a sophomore Lit. major in Arts and Crafts. Her plans call for following Tom through thick and thin and putting her foot down (on his head).

GARY GOLDBERG

Gary Goldberg who lives in Denver, Colorado, is a freshman in the College of Arts and Sciences. He is majoring in mathematics and at present has a 2.7 grade average. Gary has worked as finanicial manager of the *Engineer* for the past year.

JEAN LABE

Jean Labe, IBM secretary for the magazine, is a freshman in Arts and Science. She is pinned to Ron Steinberg, Assistant Business Manager on the staff, but she refuses to take orders from him inside or outside of the office. Jean's major is education and her hobbies are hi-fi, miniature golf, swimming, and bowling (if nobody keeps score). She lives in Denver and has no plans for the immediate future beyond 1984.

SUSAN PETERSEN

Susan Petersen is a Sophomore from Pueblo, Colorado. She served as a secretary the last part of last year and is currently a secretary. She is a member of Kappa Kappa Gamma, national girls' fraternity. Elementary education is Susan's major.

Outstanding Engineers

(Continued from page 24)

DALE CURTIS, a junior in civil engineering, was responsible for the planning and execution of last year's Engineers' Days Banquet. An active member of AES, Dale is also prominent in the American Society of Civil Engineers, currently holding the treasurer's position. He is also president of Delta Sigma Pi. Future plans include a major interest in hydraulogy with possible graduate study in that field. His plans also include his wife and four-month-old daughter. Dale believes that "One of the contacts an engineer has with other engineers is through the professional and other activities in the social and business world," and stresses the importance of active participation in these groups due to the direct correlation between effort put into the group and benefit derived.

TANGLED TEASERS

FOR TWISTED MINDS

By **JOHN FIELDER**

E.E. & Business '62

Since finals are a good two days away and the girls are all getting a suntan, you might as well relax for a few minutes and earn some money. All you have to do is ask your next door neighbor's wife how to work a few simple problems. Then you write down what she says and drop it in the *Engineer* office by May 26, 1961 A.D.

Along with the answers to the problems you should include the method of solution as this is also considered in judging. Actually they are not very hard even though you might think so at first glance. Ten dollars will be given for first place, four dollars for second, and only one little dollar for third place.

The winners of the last contest have not been picked yet but they, along with the winners of this contest, will be notified by mail. The quicker you get your solutions in, the better your chance of winning so start working now.

The first problem is an exam question which is given to all seniors at one of our neighboring universities.

1

Three farmers rented a pasture for a fixed amount, each to pay in proportion to the stock pastured. First month, A put in 3 horses and B and C each some horses, B paid \$6, A and C defaulted payment. Next month, each put in one more horse, C paid \$7.20. A and B defaulted payment. Next month, each put in one more horse, A paid \$5, B and C defaulted.

Required:
(1) rent of pasture per month
(2) number of horses B and C each put in during the first month
(3) amounts A. B, and C owed for unpaid service.

* * *

2

The faces of a solid figure are all triangles. The figure has nine vertices. At each of six of these vertices, four faces meet, and at each of the other three vertices, six faces meet. How many faces does the figure have?

* * *

The third problem is in keeping with the modern trend in the Physics department.

3

A new kind of atom smasher is to be composed of two tangents and a circular arc which is concave towards the point of intersection of the two tangents. Each tangent and the arc of the circle is 1 mile long. What is the radius of the circle?

One of a series

Interview with General Electric's

Francis J. Boucher

Manager-Manufacturing Personnel Development Service

How Good Is Your Best Job Offer . . .

Q. Mr. Boucher, with all the job interviews a graduating engineer goes through, how can he be reasonably sure he has made the right choice?

A. This is a good question because few seniors have enough work experience in industry, government and educational institutions to allow them to make a fully reasoned choice. However, I think the first step is to be sure that short-term factors like starting salary and location don't outweigh long-range factors like opportunity and professional growth. All of these factors should be evaluated *before making a final commitment.*

Q. But you do feel that starting salary is important?

A. Very much so. If you are married—it may be an even greater consideration. But you should also look beyond starting salary. Find out, for example, if the company you are considering has a good salary administration plan. If there is no way of *formally* appraising your performance and determining your appropriate rewards, you run the risk of becoming dissatisfied or stalemated due to neglect of these important considerations.

Q. What considerations do you feel should be evaluated in reaching a job decision?

A. Let me refer you to a paper written by Dr. L. E. Saline, now Manager of Information Systems in our Defense Systems Department. It is titled "How to Evaluate Job Offers." (Incidentally, you may obtain a copy by writing as directed in the last paragraph.) In it, Dr. Saline proposes six questions—the answers to which should give you much of the information you'll need for an objective job-offer evaluation. He suggests you determine . . .

- to what degree will the work be challenging and satisfying?
- what opportunities are available to further develop abilities?
- what opportunities are there for advancing in the Company (and how dynamic the Company is in the marketplace is an important aspect of this question).
- what salary potentials are possible with respect to the future?
- what about geographical location—now and in the future?
- what effort does the Company make to establish and maintain a professional climate?

There is more to these questions than meets the eye and I think you would enjoy reading Dr. Saline's paper.

Q. What about the openings on defense projects that are listed in the various magazines and newspapers?

A. Presumably, there will always be a need for technical manpower in the defense business. But I want to point out to you that most of these opportunities are for experienced personnel, or personnel with specific additional training received at the graduate level.

Q. How do you feel about training programs? Do they offer any particular advantages over any other offer I might accept?

A. I feel training programs are particularly helpful in easing the transition from an academic to a business environment. Of course they provide formal training designed to add to the individual's basic fund of knowledge. They also provide working experience in a variety of fields and a broad knowledge of the company concerned and its scope of operations. Upon completion, the individual is generally better prepared to decide the direction in which he will pursue his professional career.

General Electric conducts a number of training programs. Those that attract the greatest number of engineers are the Engineering and Science, Manufacturing, and Technical Marketing Programs. Each combines a formal, graduate-level study curriculum, on-the-job experience, and rotating assignments. There is little question in my mind that when an engineer completes the Program of his choice, he is far better prepared to choose his field by interest and by capability. I might also add that because of this, he is more valuable to the Company as an employee.

Q. Then you feel that a training program is the best alternative for a graduating engineer?

A. Not always. Some seniors have already determined the specific field they are best suited for in terms of their own interests and capabilities. In such cases, direct placement into this specific field may be more advantageous. Professional self-development for these employees, as for all General Electric technical employees, is encouraged through a variety of programs including the Company's Tuition Refund Program for work toward advanced degrees, in-plant courses conducted at the graduate level, and others designed to meet individual needs.

Q. For the record, how would you rate a job offer from General Electric?

A. I've tried to get across the need for factual information and a long-range outlook as the keys to any good job evaluation. With respect to the General Electric Company, seniors and placement offices have access to a wide variety of information about the Company, its professional environment and its personnel practices. I think qualified seniors will also discover that General Electric offers professional opportunity second to none—and starting salaries that are competitive with the average offered throughout industry today. From the above, you can see that I would rate a job offer from General Electric very highly.

Want more information about General Electric's training programs? You can get it, together with a copy of Dr. Saline's paper "How to Evaluate Job Offers" by writing to "Personalized Career Planning," General Electric Company, Section 959-15, Schenectady 5, New York.

GENERAL ELECTRIC