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The Importance of Electrokinetics in Mineral Flotation

S. C. SUN* AND G. PURCELL**

Early in 1959 a Polish engineer, Romuald Cebertowicz [1] flew to Rome hoping to convince the Italians that his "electropetrification" method might stabilize the tilt of the Tower of Pisa at its present elegant and lucrative angle. He planned to inject a plastic-like silica gel into the loose volcanic soil beneath the tower and apply a strong electric field to the ground. This would cause the gel particles to spread evenly, and they would then harden to form the foundation. Cebertowicz had already used the electropetrification method for ground consolidation, and in so doing he was making good use of an electrokinetic phenomenon known as electrophoresis.

Introduction

Electrokinetic phenomena provide a means of measuring the electrical potential difference existing at interfaces of solids and liquids or air and liquids. An excess of positive charges is produced on one side and an excess of negative charges on the other side of the boundary layer, the distribution constituting an electrical double layer. Electrokinetic phenomena, as the name implies, concern the effects of motion on the electrical double layer. This movement can be brought about mechanically in two ways: an E.M.F. can be generated either by forcing liquid past a stationary solid surface (streaming potential) or by allowing solid particles to move through a liquid at rest (sedimentation potential). In addition there are two electrical methods: moving a liquid against a fixed solid surface (electro-osmosis) or moving solid particles through a liquid at rest (electrophoresis).

Most of the work on electrokinetics in the last decade has been carried out using the streaming potential method. This lends itself to precision measurement since the quantities involved in the computation are measurable with greater accuracy and with less difficulty than the experimental data for the other three methods.

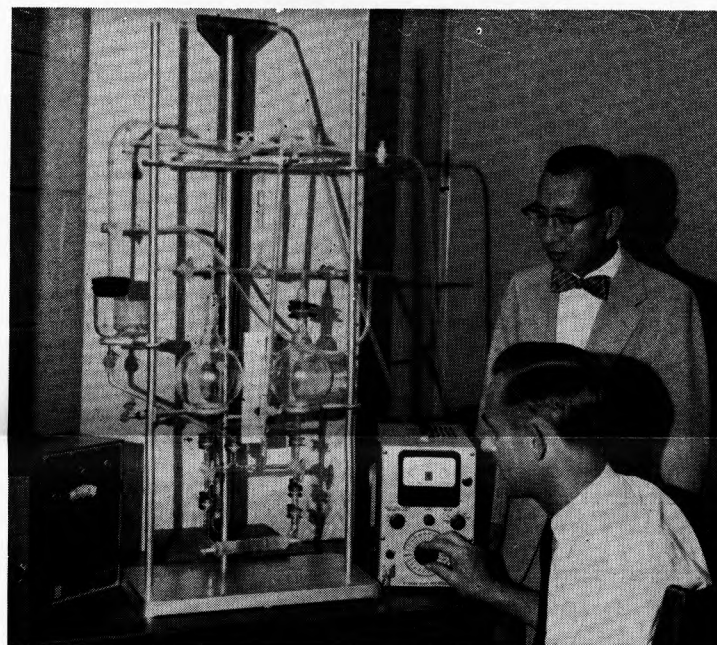
Reuss [36] in 1808 noted that when an electric current was passed through an earthenware diaphragm water was transferred from the anode to the cathode chamber. Porret [33] observed the same phenomenon in 1816 when he used a sand diaphragm. Wiedemann [42] and Quincke [34] made quantitative measurements of this electro-osmosis phenomenon. Quincke first showed that the water might travel in either direction depending upon the nature of the solid used—an observation that led him to the theory of the existence of an electrical double layer across the interface, the size of which might be different for different substances. This theory was first quantitatively expressed by Helmholtz [20] in 1879 and was modified slightly by later investigators such as Perrin [32], Lamb [25], and Smoluchowski [38].

Towards the end of the nineteenth

century the question of colloidal stability began to claim the attention of many scientists. Schulze [37] and Linder and Picton [26] had shown that colloids are extremely sensitive to small amounts of electrolytes and that the particles of these colloids move in an electric field. The effectiveness of the electrolytes as flocculants was determined (with a few exceptions) by the valency of the ion of opposite charge to the colloid particle, the flocculating effect increasing exponentially with increase of valency. Interest in electrokinetic research was stimulated when Hardy [18] pointed out in 1900 that the stability of the sols is closely connected with their electrophoretic mobility.

In 1910 Gee and Harrison [15] and Harrison [19], in developing their electrical theory of dyeing, used the stream-

(Continued on page 2)



Dr. Sun, standing, and Mr. Purcell chart measurements on the streaming potential apparatus.

Historical Background

* Professor of Mineral Preparation.

** Graduate Assistant in Mineral Preparation.

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The Importance of Electrokinetics

(Continued from page 1)

ing potential method for determining the electrokinetic potential on cotton, silk, and wool fibers against pure water and also against solutions of various electrolytes and dye-stuffs. They packed fibers into a cell between two platinum electrodes and measured the E.M.F. set up when liquid was forced through. They found that (a) acids increase the charge on positively charged fibers and decrease it on negative fibers, (b) all acids act the same when the hydrogen ion concentration is the same, (c) bases act oppositely to acids, (d) when a salt is used as electrolyte, ions of the opposite charge to that of the fiber have most effect and the sign of charge may be reversed by such ions, and (e) polyvalent ions have more effect than monovalent ions.

In this country Briggs [3] was one of the first to study electrokinetic potentials by the streaming potential method. His apparatus was subsequently modified by Gortner [16], Fuerstman [6], and Zucker [43].

FUNDAMENTAL CONSIDERATIONS

Colloidal particles in aqueous media are charged, the process of charging being spontaneous. Michaelis [28] suggests three fundamental sources of charge on the solid side of the solid-liquid interface:

1. Residual valencies causing oriented adsorption.
2. Forces of dissociation causing exchange adsorption.
3. The spontaneous distribution of ions at the free surface.

Another charging mechanism that has been suggested is the one due to friction between particles and medium arising from Brownian movement. Regardless of the charging mechanism, the whole system is electrically neutral; and, in addition to the possible motion of colloidal particles in an electrical field, the motion of the gegenions, or ionic atmosphere of the particles, must be considered. This movement of ions will be in the opposite direction to the particle.

Double Layer

According to the Helmholtz theory [20] the electrical double layer at a solid-liquid interface is analogous to the two plates of an electrical condenser, the potential of which is generally termed the electrokinetic or zeta potential. The theory assumes that the double layer is of atomic thickness, the inner layer of charges being adjacent to the surface of the solid and fixed by surface forces to it, and the single outer movable layer consisting of charges of opposite sign contained in the liquid. This model assumes a constant capacity, but later electrocapillary work proved that the capacity was not constant. Gouy [17] pointed out that the ions of the double layer could not be concentrated at a definite distance from the surface because there must be an equilibrium between the electrical forces that are responsible for the existence of the double layer and the osmotic forces that tend to maintain homogeneity. Consequently there can be no sudden change in the concentration of any kind of ions in the vicinity of the double layer, but merely a gradual increase of concentration of ions of one sign and a decrease of ions of the other sign. The density of the electrical charges in the ion atmosphere decreases according to an exponential law and not linearly as postulated by Helmholtz. Chapman [4] developed Gouy's idea and derived an expression for the equilibrium distribution of ions in such a diffuse layer. This was very similar to that used later by Debye and Hückel [5] to determine the distribution of ions in the ionic atmosphere around a given ion. In 1924 Stern [39] suggested a type of double layer that is a combination of the simple Helmholtz fixed layer and the Gouy-Chapman diffuse layer.

Figure 1 illustrates the distribution of charges surrounding a negatively charged particle, which gives rise to an electrical double layer. The double layer consists essentially of three parts:

1. Negative charges in the inner circle (a) of the illustration are potential-determining ions, which may be regarded as part of the lattice.
2. Counter ions, held close to the solid surface and separated from it by a solvating layer of strongly bound water molecules, occupy a plane known as the Stern plane (b), which is only a few angstroms thick.
3. Counter ions form the diffuse or Gouy layer (c). It is convenient to think of a shell of ions equivalent in action to the diffuse layer, the distance from the shell to the surface of shear being known as the thickness of the double layer. This thickness (d) is inversely proportional to the square root of the ionic strength and is about 1000 Å thick in 10^{-5} molar solutions.

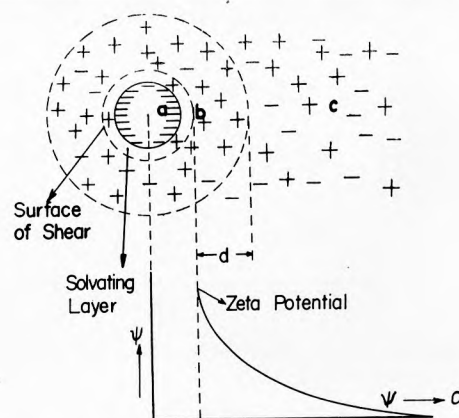


FIGURE 1. The electrokinetic potential and the electrical double layer. a: potential determining ions; b: counter ions in the Stern plane; c: counter ions in the diffuse or Gouy layer.

When the solution moves relative to the solid, shear takes place between the Stern plane and the Gouy layer, and the diffuse ionic atmosphere is carried along with the liquid. The electrical potential at the slipping plane with respect to a point far out in the liquid is called the zeta potential. The total potential across the double layer, the surface potential ψ_0 , is determined by the concentration of potential-determining ions in the solution. The zeta potential is smaller in absolute value and depends not only on the surface potential but also on the total electrolyte concentration, the location of the slipping plane, and the charge distribution. Figure 2 shows that the zeta potential is not closely related to the surface or electrochemical potential and may even be of opposite sign.

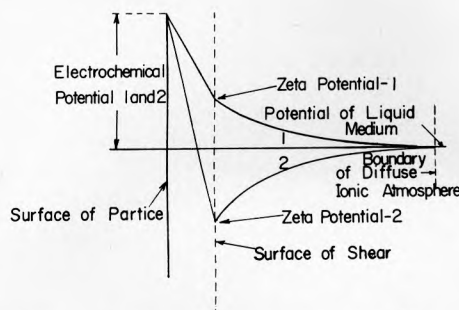


FIGURE 2. The electrical potentials as a function of distance from a charged particle in a liquid medium.

Streaming Potentials

When a liquid is forced through a porous plug made of crystalline material, a potential difference (the streaming potential) can be measured between two electrodes placed at either end of the plug. The liquid stream carries along with it the charge in the diffuse double layer and is the bearer of an electric convection current. As a consequence of the transport of charge a potential difference arises between the ends of the plug, which causes a conduction current through the plug in a direction opposite to the convection current. In the stationary state the convection current, which is proportional to the pressure difference P causing the liquid flow, just counterbalances the conduction current, which is proportional to the potential difference E across the plug.

The factor of proportionality can be determined mathematically [24] and is equal to:

$$\frac{E}{P} = \frac{\epsilon \xi}{4 \pi \eta \lambda}$$

where:

- E = streaming potential
- P = applied pressure difference
- η = viscosity
- ϵ = dielectric constant
- λ = specific conductance
- ξ = zeta potential

In aqueous systems at 25°C the equation becomes:

$$\xi = 9.69 \times 10^4 \times \frac{E \lambda}{P} \text{ millivolts}$$

Conditions that must be satisfied for the expression to be valid are:

1. Flow of liquid must be laminar.
2. Size of pores must be many times the thickness of the double layer.
3. Surface conductance should not be important in determining the conduction current through the plug.

Experimentally the values of λ , E , and P must be determined.

It has already been pointed out that the stability of sols is closely connected with the electrical double layer, and colloidal scientists have, in the past, been responsible for most of the work on electrokinetics. One need mention only a few of the everyday materials now classed as colloids to realize their importance: clays, soils, milk, butter, cheese, dough, ink, paint, glue, fog, mist, cloud, smoke, silk, cotton, wool. However, electrokinetic studies are no longer confined to colloids, and the work now being done by research workers in the field of mineral preparation is making a very significant contribution to our knowledge of adsorption phenomena at solid-liquid interfaces.

FLOTATION

Flotation in its simplest form is a convenient way of separating one mineral from another based on the difference in wettability of their surfaces. The introduction of air into an aqueous mixture of the two minerals will result in the attachment of the hydrophobic mineral to the air bubbles which are subsequently floated to the surface. The addition of a collector facilitates this process because, in most cases, the collector is selectively adsorbed by the valuable mineral which then becomes sufficiently hydrophobic for flotation. Other reagents used in flotation are activators and depressants. Both of these groups work on selected minerals to induce collection in the case of the activator or to discourage collection in the case of the depressant. Because most minerals adsorb hydrogen and hydroxyl ions over some part of the pH range, it follows that hydrogen or hydroxyl ions often act as depressants or activators.

Flotation theory has always lagged behind industrial practice; this is understandable in such a complex three-phase system. To determine the adsorption of flotation reagents on mineral surfaces by chemical methods or even by the modern radioactive tracer technique is time-consuming and sometimes impractical. Furthermore, adsorption measurements can give the total amount of the adsorbed reagent but can not provide information of the distribution of the adsorbed ions. In recent years electrokinetic studies have been made on a number of minerals, chiefly insoluble oxides, to gain some insight into the mechanism of their flotation. Since zeta potential is dependent on adsorption and orientation of ions at a solid-liquid interface, its variation under different conditions

should throw some light onto the flotation mechanism. As early as 1915 Ralston [35] suggested that electric charges must be considered in the explanation of flotation. Ince [21] used a Burton tube in 1930 to estimate the electric charge of slime particles. Sun [40], however, in 1943 was the first in the mineral preparation field to make a systematic measurement of zeta potential and to propose an ionic theory for explaining the mechanism of slime coating. This work was done with the electrophoresis technique. Since then, electrokinetics have been accepted as an effective tool for flotation research. Some of the significant findings are cited in the following discussion.

Cassiterite

In 1946 Sun [14] measured the electrophoretic mobilities of several minerals, particularly cassiterite, in solutions of various flotation reagents including collectors, activators, depressants, and pH regulators. He was able to obtain a correlation between zeta potential and flotation phenomena. Two of his results serve to illustrate the correlation:

1. The zeta potential of cassiterite increased in negative value with successive additions of sodium oleate, sodium laurate, sodium pelargonate, cupferron, or alpha amino valeric acid. The flotation recovery paralleled in degree the magnitude of change of the zeta potential for each of these collectors.

2. Sodium sulfate, 50 mg./liter, increased in negative value the zeta potential of cassiterite and increased in positive value the zeta potential of cassiterite in 50 mg./liter of laurylamine hydrochloride over a large pH range. Furthermore, the maximum zeta potential in the amine alone occurred at pH 8.3, while Na_2SO_4 occurs at pH 7. The flotation of cassiterite with amine was enhanced by Na_2SO_4 , and the maximum flotation rate was shifted from pH 9 to pH 8 in the presence of sodium sulfate.

O'Connor and Buchanan [30], using a streaming potential apparatus, found that the zeta potential of three cassiterite samples differed greatly from one another. They ascribed this difference to the variation in chemical composition, which indicates that the flotation behavior of cassiterite is influenced by its geographical source.

Quartz

Quartz has been widely used as a specimen for studying the mechanism of activation and depression by means of electrokinetics. Gaudin and Fuerstenau [12] found that quartz is negatively charged in water and in most dilute aqueous solutions. Hydrogen and hydroxyl ions are potential-determining ions, and the isoelectric point of quartz occurs at a pH of 3.7. Barium ions can change the sign of the zeta potential at a critical concentration, and aluminum ions behave likewise at a smaller concentration. The affinity of metallic cations for the surface of quartz in decreasing order is therefore Al^{+++} , Ba^{++} , Na^+ . Gaudin and Chang [10] found that laurate ions are adsorbed on quartz in the absence of activator, but the fact that the mineral does not float indicates that laurate ions are probably not attached to the quartz surface. They also found that barium adsorption is controlled by the pH and concentration of barium ions but is independent of laurate ions. The adsorption of laurate ions, however, is markedly affected by the presence of barium ions. Plotting zeta potential against concentration of electrolyte for sodium chloride and sodium laurate gave identical curves. The potential was unaffected until the total ionic strength of the solution increased above 10^{-4}

equivalents per liter. Because the zeta potential does not become more negative under these conditions, laurate ions do not lie next to the quartz surface. In the presence of barium nitrate, however, the zeta potential is dependent on the pH and concentration of barium nitrate but is not affected by laurate ions up to a concentration of approximately $3 \times 10^{-4} \text{N}$. (Precipitation of barium laurate at this concentration occurs at pH 10.) If there were specific adsorption of laurate ions at the quartz surface, the zeta potential would become more negative with an increase of laurate ions. Thus the laurate ions are probably held next to the surface of barium-activated quartz only by association with specifically adsorbed barium ions in the Stern layer. On the basis of this mechanism the authors postulate that only multivalent cations can function as activators in the soap flotation of quartz.

Continuing this study, the same investigators [13], using a cationic collector, measured the zeta potential of quartz for various amounts of dodecylammonium acetate at pH 4, 7, 10, and 11. The concentration at which the zeta potential decreases abruptly and changes sign is shifted to lower concentrations of collector as the pH increases. Zeta potentials of quartz in solutions of dodecylammonium chloride and sodium chloride were compared at neutral pH. Plotting zeta potential against logarithm of concentration gave similar curves at low concentrations; as the concentration increases, however, the dodecylammonium chloride reverses the sign of zeta potential, while sodium chloride reduces it without altering its sign. In alkaline solution dodecylammonium ions abruptly reduce the value of zeta potential at a concentration well below that which increases the ionic strength of solutions. To determine whether this reduction was due to compression of the double layer or to some other cause, zeta potentials were measured in solutions containing fixed amounts of collector with varying amounts of sodium chloride added specifically to compress the double layer. At a collector concentration of 10^{-4}M the zeta potential of quartz was -78 mv . This value remained constant with addition of sodium chloride until the ionic strength of the solution began to increase, at which point the zeta potential was reduced, approaching zero at infinite concentration. At a collector concentration of $5 \times 10^{-4} \text{M}$ the zeta potential of quartz was 36 mv . Addition of sodium chloride has no effect on the zeta potential until the ionic value is sufficiently changed, and then the value tends to zero. The abrupt change in the zeta potential with increasing concentration of dodecylammonium acetate does not, therefore, result from compression of the double layer. It seems that in dilute solutions dodecylammonium ions may be held to the surface by electrostatic attraction for the negative quartz surface (as are sodium ions); but at higher concentrations a new mechanism, peculiar to hydrocarbon-bearing ions, is operative. The authors suggest that at a certain critical concentration of collector ions in the double layer the ions begin to associate into bundles, which have been given the name hemi-micelles.

Fuerstenau [7], in developing his hemi-micelle hypothesis, suggests that the low concentration for abrupt change to a steep slope observed with amines is proportional to the micelle point of the amine. Ammonium ions function only as surface-inactive counter ions. Ammonium acetates, however, cause reversal of sign of zeta potential, and as the hydrocarbon chain length increases the breaks occur in more dilute solutions. The tendency to form hemi-

micelles at neutral pH was not present in the eight carbon ammonium ions.

Using quartz and a constant amount of dodecylammonium acetate as collector, Fuerstenau [8] has made an interesting comparison of change of contact angle, adsorption density, zeta potential, and flotation rate with change of pH. Contact angle is a maximum at pH 10 - 11. The adsorption density increases slowly up to pH 8, after which the increase is very rapid. (A closely packed monolayer is thought to occur at approximately pH 8.) The zeta potential becomes more negative as the pH is increased from 4 to 9; between pH 9 and 10 it decreases sharply, becoming positive at pH 10. Further increase in pH then causes the zeta potential to become negative again. The flotation rate reaches a maximum at pH 10. There appears to be excellent correlation among these four surface and flotation phenomena, which were obtained by four different investigators.

Hematite

Using electrophoresis methods, Iwasaki and co-workers [22] determined the isoelectric point of hematite as a function of pH and found this to be pH 6.7, in agreement with Johansen and Buchanan [23]. Thus hematite is positively charged below pH 6.7 and negatively charged above. In addition, Iwasaki determined the flotation of hematite as a function of the pH in 10^{-4} M solutions of dodecylammonium chloride and sodium dodecylsulfate. The anionic collector sodium dodecylsulfate gave 100% recovery from pH 2 up to pH 6 (i.e., over the range where the surface is positively charged); it then decreased sharply to less than 5% at pH 7. The cationic collector, on the other hand, gave approximately 5% recovery from pH 2 to pH 6, after which it increased rapidly to 100% at pH 7.5 to pH 12. The results illustrate the essentially electrical nature of the collector reaction with the hematite surface, a correlation which the authors also found for goethite and quartz with the same collectors.

With 18-carbon collectors at the same concentration, the pH range over which the recovery was 100% increased by almost 4 pH units; i.e., the anionic sodium octadecylsulfate gave 100% recovery from pH 2 to pH 10, and the cationic collector gave 100% recovery from pH 12 to pH 3.5. The authors attribute this to the so-called "squeezing-out" effect caused by unfavorable ionic size with respect to the associated water structure. In addition, the stronger lateral interaction of hydrocarbons of the adsorbed organic ions assists in holding the ions to the hematite surface. At reduced concentrations of 18-carbon collectors the critical pH values tend to approach the isoelectric point.

Corundum

Modi and Fuerstenau [29] found that the zeta potential is zero at pH 9.45 and is positive at all pH values below this. Hydrogen and hydroxyl ions are potential-determining ions. Sodium chloride and sodium nitrate are surface-inactive indifferent electrolytes for corundum, the chloride and nitrate ions functioning as counter ions and reducing the zeta potential to zero at higher concentrations. Barium ions are surface-active indifferent ions, since they reverse the sign of zeta potential at pH 10; however, they are not attracted to the surface in neutral solutions. Similarly, SO_4^{--} ions are specifically adsorbed only when the surface is positively charged. The same authors [9] investigated the effect of certain 12-carbon anionic and cationic surface-active electrolytes on the zeta potential of corundum at different pH values.

Sculpture in Museum



THE ACQUISITION of "Miners," a piece of wood sculpture, for the Mineral Industries Art Gallery has been announced by David E. Snell, Curator of the Mineral Industries Museum. The purchase was made in accordance with Museum policy of acquiring a notable collection of art centered on the mineral industries theme.

The artist Heri Bert Bartscht, a native of Germany currently residing in Dallas, Texas, is considered one of the foremost sculptors of the southwest. "Miners," executed in bois d'arc, represents the cross section of a coal mine.

Their results indicate that organic ions are adsorbed appreciably only under conditions where the solid and organic ions are charged oppositely. Adsorption takes place as individual ions until a sufficiently high concentration is attained in the Stern layer to permit association of their hydrocarbon chains into hemi-micelles. The authors discuss an adsorption mechanism involving electrostatic attraction and hydrocarbon chain association. O'Connor [31] found that the surface charge on corundum could be reversed by ignition.

PRESENT INVESTIGATION

The object of the research now contemplated is to measure the electrokinetic potential of pure titanium dioxide in aqueous solutions containing 18-carbon fatty acid soaps. The acids concerned—namely stearic, oleic, linoleic, and linolenic—have none, one, two, and three double bonds respectively and from a chemical point of view are insoluble. The relative effectiveness of these acids as collectors in mineral flotation has been determined, with some small measure of agreement, by a number of investigators; but no valid explanation has been given concerning the significance of the double bonds.

Gaudin and Cole [11] established that oxidizability of the double bonds was not a factor, as had once been thought. Bhrany and Rao [2] suggested that the saturated stearic acid molecules are adsorbed with a perpendicular orientation to the mineral surface; oleic acid molecules, having two centers of attraction, are in a kneeling position and therefore cover a

Three on Sabbatical

THREE professors in the College of Mineral Industries are currently on sabbatical leave.

HAROLD D. WRIGHT, associate professor of mineralogy, has been awarded a Fulbright grant for a year of research. He will be engaged in studies at the University of Oslo, Norway, concerned with trace elements in rocks and minerals, utilizing radioisotopes. His work will include studies of some unusual igneous rocks in the Oslo area noted for their abnormal content of uranium, thorium, and rare earth elements. Dr. Wright will also conduct experimental studies of trace level solid solubility of some base and precious metals in alkali halides and other minerals. In connection with this work he will spend three months this fall at the Max Planck Institute for Chemistry at Mainz, Germany.

AMOS J. SHALER, head of the Department of Metallurgy, is spending the year in Europe with Brussels, Belgium as his headquarters. He plans to do research in powder metallurgy at the laboratories of European Research Associates, S.A. In addition, Dr. Shaler plans to work on completion of the revision of the textbook, "Metallurgy for Engineers," of which he is co-author. He will travel extensively, and will visit industrial laboratories and metallurgy departments of universities in western Europe.

DONALD C. JONES, director of Mineral Industries Continuing Education, has been granted a leave for the fall semester. Mr. Jones plans to travel and study and, in addition, will do some writing.

R. B. HEWES, professor of Mineral Industries Continuing Education, will serve as acting director during Mr. Jones' absence. Mr. Hewes, a graduate of Penn State, has served on the faculty since 1939.

larger area than the stearic acid molecules. Oleic acid is thus the better collector. Mallikarjunan and Ramachandran [27] upset this theory when they found that equilibrium contact angle on calcite was attained at the same rate with linoleic and linolenic acid. Sun [41] determined that the effectiveness of these four fatty acids in increasing order is stearic, oleic, linoleic, and linolenic for thirty-six out of thirty-seven minerals tested; but he did not attempt to explain the mechanism.

A very generous grant from the Mineral Industries Experiment Station, for which the authors would like to express their gratitude, has made it possible to construct the streaming potential apparatus shown in the photograph on page 1. It is hoped that the use of this apparatus will throw some light on the mechanism of 18-carbon fatty acid flotation.

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Conferences on Campus

SEVERAL large conferences were held at the University during the summer and early fall months under the sponsorships of various departments of the College of Mineral Industries.

The Eastern Section of the Seismological Society of America met June 27-29 under the sponsorship of the Department of Geophysics and Geochemistry. This meeting was held just before and in conjunction with the International Symposium on Stress Waves sponsored here by the Office of Ordnance Research.

About 40 scientists from North America and Europe attended the Conference on Zeolites held July 16-18. The conference was under the direction of Joseph V. Smith, associate professor of mineralogy. About 30 papers were presented concerning the properties, occurrence, and stability of zeolite minerals.

The Ninth Annual Drilling Symposium was held October 8-10 under the auspices of the Departments of Mining at the Colorado School of Mines, the University of Minnesota, and The Pennsylvania State University.

The symposium was under the direction of Howard L. Hartman, head of the Department of Mining. Technical sessions included the following topics: Improving core recovery; statistics and operations research in exploration; slim holes, large holes, and air drilling; and bit design and drilling in unconsolidated materials.

The Twenty-first Technical Conference on Petroleum Production was held August 24-26 to coincide with the Drake Centennial. The conference, which was co-sponsored by the Department of Petroleum and Natural Gas and the Pennsylvania Grade Crude Oil Association, was under the direction of R. L. Slobod, head of the department.

Carl Gatlin, who received his Ph.D. from Penn State this year, presented a paper, co-authored by Dr. Slobod, which covered their work on the alcohol slug process. Other technical papers covered the combustion drive technique and miscible phase displacement.

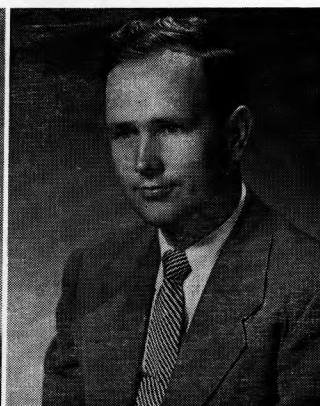
Miss Genevieve Blatt, Secretary of Internal Affairs of Pennsylvania, spoke on the early history of the oil industry at a banquet.

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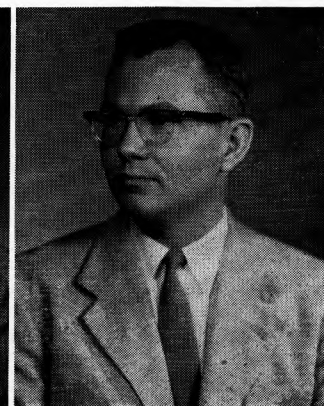
Changes in the Division of Mineral Technology



Weyl



Walker



Palmer

WOLDEMAR WEYL, chairman of the Division of Mineral Technology since 1948, has resigned that position to accept an appointment as research professor in the College of Mineral Industries. Dr. Weyl came to Penn State in 1938 from the Kaiser Wilhelm Institute in Berlin, Germany. He is a graduate of the Darmstadt Technische Hochschule with his doctorate in chemical engineering from the Aachen Technische Hochschule. Dr. Weyl has conducted extensive research in the field of solid state chemistry, dealing particularly with surface phenomena and defects in crystals and glasses, and with fluorescence, light absorption, and solid phase reaction which have led to the publication of more than 100 papers.

PHILIP L. WALKER, who has served on the faculty since 1949 and has headed the Department of Fuel Technology since 1954, succeeds Dr. Weyl as chairman of the Division of Mineral Technology. Dr. Walker received his B.S. and M.S., both in chemical engineering, from The Johns Hopkins University and his Ph.D. in fuel technology from Penn State. His research has been concerned primarily with properties and allayment of coal dust, gaseous combustion

studies on flame velocity and flame stability, kinetics and reaction mechanism of carbon combustion deposition from carbon monoxide, X-ray diffraction studies on carbons, gas absorption of carbon, and graphitization of carbon.

HOWARD B. PALMER, associate professor of fuel technology, has been named head of that department to succeed Dr. Walker. Dr. Palmer, who came to Penn State in 1955, received his B.S. from Carnegie Institute of Technology and his Ph.D. from the University of Wisconsin. He has done research on liquid-vapor equilibria and the critical region on the kinetics of gaseous reactions at high temperatures as studied by shock wave methods; on radiation from hot gases; on the action of inhibitors and accelerators in carbon monoxide combustion; on the kinetics of carbon deposition in high temperature systems; and on the burning rate of a solid propellant containing free hydrogen atoms. His research now in progress includes the role of radiation in the combustion of pulverized fuels and on the reactions of gaseous free radicals.

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M. I. COLLOQUIUM SERIES PRESENTS VARIETY OF SUBJECTS

M. E. BELL*

THE MINERAL INDUSTRIES COLLOQUIUM series brought to the University during the past academic year numerous eminent scientists who spoke on a wide variety of scientific subjects.

The series was instituted in 1954 to broaden and extend the knowledge of the staff and students by providing speakers in the various branches of science, engineering, and technology related to the activities of the College. Not only has the series provided a platform for distinguished outside speakers, but also it has enabled the different departments of the College to discuss work of common interest. Further, the colloquia have provided a means

by which members of the College would get to know about developments and problems in sections of the College other than their own.

When the subject is of even more general interest than usual, the colloquium is arranged and announced jointly with one or more of the other colleges at the University. In this way mutual research interests among colleges have been encouraged. When an outside speaker has not been scheduled three weeks before the date of a colloquium, the various departments of the College, selected in rotation, are requested to provide a speaker from their staff or graduate students. This arrangement has resulted in broadening the knowledge of the departmental research programs among the members of the College.

The colloquia are held every Friday at 4 p.m. in the Mineral Industries Auditorium. The Mineral Industries Experiment Station has general charge of the arrangements. Within the limits of available funds, the Experiment Station can offer an honorarium to assist outside speakers in making the journey to State College when necessary and appropriate.

Colloquia for the current academic year began September 25, 1959 with a talk by R. G. Rigby, Director of Research Canadian Refractories, Ltd., on "Volume Expansions in Solid State Reactions."

A listing of the Colloquium speakers for the past academic year will give an idea of the scope of the program being presented.

* Assistant Dean for Research and Director Mineral Industries Experiment Station.

Staff Activities

B. F. OLIVER, assistant professor of metallurgy at the University, presented a paper at the Conference on Sintering held at the University of Notre Dame in August. With A. J. Shaler, head of the Department of Metallurgy, as co-author, Dr. Oliver discussed the significance of surface variables and interactions between grain boundaries and free surfaces in a sintering model.

B. F. HOWELL, head of the Department of Geophysics and Geochemistry, has been elected Secretary of the Seismology Section of the American Geophysical Union for the triennium 1959-1962.

RUSTUM ROY, professor of geochemistry, presented two papers at the International Union of Pure and Applied Chemistry held in Munich August 31. The papers described work done at Penn State, one on high pressure synthesis of new inorganic materials, and another on compounds of the rare earths. While abroad Dr. Roy visited laboratories in England, Holland, Germany, Eastern Europe, and the Soviet Union. ARNULF MUAN, associate professor of metallurgy, also attended the meeting.

HANS A. PANOFKY, professor of meteorology; LOWELL KRAWITZ, research assistant in meteorology; and PAUL R. JULIAN, graduate student, are authors of a paper, "The Relation Between the Lower Stratosphere and the Troposphere," presented at the Conference on Stratospheric Meteorology held August 31 to September 3 in Minneapolis, Minnesota. Mr. Julian also gave a paper, "Tropospheric Behavior during the Arctic Stratosphere Warning Phenomena," and Edward S. Epstein, graduate student in meteorology, spoke on "Vorticity and Vertical Motion in the Lower Stratosphere."

H. MAUZEE DAVIS, professor of chemical metallurgy, was one of eight faculty members cited for excellence in teaching in a special ceremony at the June, 1959, Commencement Exercises at Penn State. He received an award of \$100 in addition to the citation.

Dr. Davis is a graduate of Oklahoma University, where he also earned his M.S. He was granted the Ph.D. by the University of Minnesota in 1934. In 1936 he joined the faculty of Penn State and was named to his present professorship in 1951.

Mineral Industries Colloquium — July 1958 - May, 1959

- July 18, 1958—Dr. S. C. Jain, Visiting Professor of Physics, University of Illinois, Urbana. "Production and Diffusion of Lattice Vacancies in Alkali Halide Crystals."
- October 17, 1958—Dr. J. E. Burke, Manager of Ceramic Studies, General Electric Company, Schenectady, New York. "Sintering and Grain Growth in Oxides."
- October 22, 1958—Mr. S. S. Wadman, Jr., Philips Research Laboratories, Eindhoven, Holland. "High Pressure Studies at the Philips Research Laboratories, Eindhoven, Holland."
- October 28, 1958—Leon Long, Lamont Geological Observatory, Columbia University. "Application of Radioactive Age Determinations to Solving the Metamorphic History of the Eastern U. S."
- November 14, 1958—Dr. A. Taylor, Westinghouse Research Laboratories. "Some X-ray Studies of Complex Alloy Systems."
- November 21, 1958—Mr. Albert Carlin and Mr. Sidney Teweles, U. S. Weather Bureau, Washington, D. C. "Recent Occurrences of Explosive Warming in the High Stratosphere."
- November 25, 1958—Dr. J. H. Chester, Assistant Director of Research, The United States Steel Companies, Ltd., Sheffield, England. "Factors Controlling Iron Oxide Deposition in Open Hearth Furnaces."
- December 2, 1958—Dr. Martin Elliott, Director of the Institute of Gas Technology. "Long Range Energy Supply with Particular Emphasis on Gaseous Fuels."
- December 5, 1958—Dr. Howard A. Meyerhoff, Executive Director, Scientific Manpower Commission. "Wanted: A National Mineral Policy."
- December 12, 1958—Dr. G. W. Brindley, Head of the Department of Ceramic Technology. "Studies of Some Mineral Reactions."
- December 15, 1958—Dr. F. W. Neilson, Physicist with The Sandia Corporation. "Explosively Shocked Ferroelectrics."
- January 8, 1959—Dr. H. Flood, Professor of Inorganic Chemistry and Director of the Institute of Silicate Science at the Norwegian Institute of Technology in Trondheim. (Joint Chemistry and Mineral Industries Colloquium.) "Oxygen Fe^{++} — Fe^{+++} Equilibria in Spinels."
- January 9, 1959—Dr. J. C. Griffiths, Head of the Department of Mineralogy. "Computers and Their Availability."
- January 16, 1959—Dr. George H. Morrison, Head Inorganic and Analytical Chemistry, Sylvania Electric Products, Inc. "Neutron Activation Analysis for Trace Elements."
- February 6, 1959—Dr. Paul Weisz, Research and Development Department Socony-Mobil Laboratories. "Diffusion Effects in Porous Reaction Systems."
- February 13, 1959—Dr. W. B. Zinman, Physical Chemist, Aerosciences Laboratory, Missile and Ordnance Systems Department; General Electric Company. "The Reaction of Carbon and Active (Atomic) Nitrogen."
- February 20, 1959—Dr. E. Willard Miller, Head of the Department of Geography. "World Patterns and Trends in Energy Consumption."
- February 25, 1959—Dr. Hessel de Vries, Professor of Biophysics, The Natuurkundig Laboratorium, University of Groningen, The Netherlands. (Joint College of Liberal Arts and College of Mineral Industries Colloquium.) "Recent Developments in the Techniques of Radiocarbon Dating in Geology and Archaeology."
- February 27, 1959—Dr. J. V. Smith, Associate Professor of Mineralogy. "The Developing X-ray Powder Data File."
- March 6, 1959—Dr. B. F. Oliver, Assistant Professor of Metallurgy. "The Role of Zone Melting in Research."
- March 13, 1959—Dr. P. L. Walker, Jr., Head of the Department of Fuel Technology. "Nature of Carbon Formed from Carbon Monoxide Decomposition over Iron."
- March 20, 1959—Dr. W. D. Kingery, Associate Professor of Ceramics, Massachusetts Institute of Technology. "Sintering in the Presence of a Reactive Liquid."
- March 24, 1959—Mr. Joseph Grumer, U. S. Bureau of Mines. "Flame Research at the Bureau of Mines."
- April 17, 1959—Dr. M. Gardner Clark, Professor of Economics, Cornell University. "The Soviet Steel Industry."
- April 24, 1959—Dr. E. I. Doucette, Bell Telephone Laboratories. "Some Electronic, Chemical, and Structural Properties of Pyrolytic Carbons."



Mineral Economics

The Cost of American Labor

JOHN J. SCHANZ, JR.*

High-Cost American Labor Versus Cheap Foreign Labor

"PROTECT American industry from cheap foreign labor" is a saying which has been heard for many decades. For some products and some industries, there has been occasional real distress created by competition from foreign commodities. Despite "cheap" foreign labor, however, the United States has been able to export goods manufactured by "high-cost" American labor to those nations paying low wages.

This apparent contradiction is readily explained by the fact that we are inclined to think of labor in terms of wages per unit of time; i.e., one dollar per day labor is "cheap" whereas thirty dollars per day labor is "costly." This ignores the fact that the true cost of labor is measured in dollars per unit of output. If the dollar-a-day man turns out one unit per day, the cost of his labor is one dollar per unit. While, if the thirty dollar per day man turns out 40 units per day, the cost of his labor is 75 cents per unit. In this way, a nation using thirty dollar per day man power can still offer its products at a lower price if the cost of any equipment utilized does not nullify the labor saving.

The development of the United States as a high-wage—high productivity nation instead of a low wage—low productivity country stems naturally from the character of the land itself and its population. There is an immediate opportunity for a high level of income per capita in a country which has a high proportion of mineral and agricultural resources to population. In the early history of the United States fertile land was available almost for the asking. This land would not only sustain the individual but would also offer an opportunity for profit. Consequently, in the early period of industrialization in the United States, labor was not only scarce but had to be attracted to the mine or the mill by relatively high wages.

As the nation's population grew rapidly, industry had to satisfy large markets while using high-cost labor. This provided an incentive for mass production of standardized goods. In this manner, the per unit cost was kept down despite the high wages paid for scarce labor, and it was possible to satisfy the tremendous demand of a growing, high-income population. Interchangeable parts, assembly lines, and automation were part of this development of American industrial efficiency.

Dissemination of The Benefits of Higher Productivity

The United States, consequently, started with a higher wage structure than would be found in densely populated, resource-poor nations. In more recent decades, as the United States continued its technologic progress and constantly increased the productivity of its labor force, the question of how to distribute the benefits of this greater output had to be answered. Two

solutions presented themselves. One was to lower prices and to keep wages constant, which would permit the consumer to buy more and more with each dollar spent. The other solution was to raise wages while keeping prices constant, which would permit the worker to purchase more with the additional dollars he earned. Naturally, there can be a compromise between these two extremes with the increased productivity being balanced by a simultaneous moderate decline in prices and moderate increase in wages.

The American laboring force has more often been attracted by the second solution than the first. The lowering of prices by the worker's company, with no wage increase, does not immediately improve the position of the individual worker, though it does increase the purchasing power of the population as a whole. The individual worker eventually benefits by the increased sales of his own company and will have improved purchasing power if all other companies follow the same policy of reducing prices rather than raising wages. It is only natural that the individual worker prefers the direct and immediate benefits of a wage increase rather than the more indefinite and slower return from lower prices. From the viewpoint of the population as a whole, raising wages in a given industry where production has increased improves the position of only those workers who work in that industry. The remainder of the population will not experience an increase in their standard of living until the greater purchasing power of these workers begins to affect the whole economy.

American Products in Foreign Trade

Within the domestic economy the distribution of additional output resulting from greater productivity through higher wages presents no problem other than the unequal distribution of the benefits as described above. When American goods enter into foreign trade or foreign goods enter American markets, however, the fact that American goods are produced by high-cost labor can affect the competitive position of American goods. Furthermore, when the prices tend to increase due to inflation, as in recent years, and wage increases are not matched by equivalent increase in productivity, the competitive situation becomes even worse.

Until very recently this has not decreased significantly the salability of American goods abroad or brought about a loss of domestic market to imported foreign goods. American products have normally been able to offer one or a combination of three things to attract the domestic or foreign purchaser—low prices, high quality, and/or technologic superiority. Low price will attract the customer because it is the lowest price for equivalent goods. High quality can command a higher price for the same item of merchandise because better workmanship or grade of material provides a greater return per dollar spent. Finally, technologic superiority will bring a high price because the

item is more complex or more advanced in design than the cheaper item.

At one time, many American products were sold at a lower price than foreign goods because the mass production methods utilized in the United States were not employed in most other industrial nations. Furthermore, American products developed a reputation both at home and abroad for quality of workmanship and materials. Finally, American products were technologically superior to the products of all but a few other nations.

As foreign nations have adopted American methods, built large modern plants, and continued to enjoy the advantage of lower wages, a new era of competition for American industry in foreign markets and at home has begun. No longer can the United States expect to have easy sales by virtue of the lowest price. Although workers in other nations will expect a greater return in wages to reward them for their greater productivity, it is to be expected that foreign wages will lag well behind their increase in productivity. Many years will probably pass before foreign wages are as high as those in the United States.

The United States still retains the advantage of producing goods of equivalent or better quality than foreign goods. This advantage, too, can be lost. The workmanship and fine materials found in American goods can be duplicated and, in individual products, have been surpassed by nations with a long history of advanced technology such as Germany. As foreign nations build new plants and train skilled workmen, their performance in such things as refining, alloying, and quality control can reach American standards. In fact, American industry should show some concern over the fact that mass production methods seem to have brought about a deterioration in American workmanship in many products. The worker no longer seems to have pride in the perfection of his work, and management seems to be more interested in new designs and models than in the performance of the current output.

Technologic superiority seems to be the last stronghold of American industry. The United States can still turn out the finest array of machinery, tools, electronic, and electrical equipment of any nation in the world. These items are noted for reliable performance and relatively low cost despite the fact that they are highly complex and the ultimate in automation. The actual and potential technologic progress of countries, such as Great Britain, the Soviet Union, and Germany, should dispel and thought that continued leadership of United States in this area is assured.

The Situation in Mining

The actual or potential increase in productivity of foreign labor coupled with low-wage rates creates an even more serious situation for the American mining industry than for other segments of industry. In dealing with mineral raw materials only two competitive weapons are available—low price or high quality. Large reserves of high-grade ore are no longer found exclusively in the United States. Instead we find the United States shifting more and more to low-grade resources while the outstanding reserves of high-grade ore are found in foreign lands—the copper of Chile, the lead of Australia, the bauxite of Surinam, the iron of Venezuela, and the oil of the Middle East. Better mining methods cannot overcome the disadvantage of low-grade ores because the more important foreign mines are utilizing the same methods. This is particu-

* Associate Professor of Mineral Economics.

larly true in the case of foreign mines developed by American mining companies.

A quality advantage for United States mineral commodities can be obtained only after processing or refining has taken place. Here, too, it can no longer be expected that petroleum products, coal, steel, nonferrous metals, alloys, or finished nonmetallics will be better prepared, refined, or alloyed in the United States than those produced in the future by foreign mineral processing plants. Technologic superiority is seldom of significance in marketing minerals or semifinished materials, with the occasional exception of new alloys or special purpose super-duty nonmetallics.

For the American mining industry the loss of export markets for mineral raw materials is not as serious as the possible influx of foreign mineral raw materials to satisfy domestic demand. The United States, which has consumed approximately half of the world's mineral production for many decades, has relied for the most part on domestic mines. Consequently, the export and import of raw materials has been relatively small compared to the total amount consumed. The bulk of our foreign trade has been the export of manufactures.

The effect of productivity and grade and size of reserves on international trade in minerals is illustrated by the American coal and oil industries. Prior to 1941, the United States was a net exporter of petroleum and its products and possessed the largest proved reserves of petroleum in the world. The fact that domestic oil was easy to find and to produce more than compensated for the high wages paid the skilled American worker. Furthermore, the quality of United States petroleum products was better than that of other producing nations. Since 1941, American petroleum engineering methods have been introduced all over the world, modern refineries have been built in many foreign countries, and highly productive, low-cost Middle Eastern oil fields have been opened up. Today, the United States finds itself a net importer of petroleum and its prod-

Mineral Industries Adds Two to Staff

Two appointments have been made to the faculty of the College of Mineral Industries this fall.

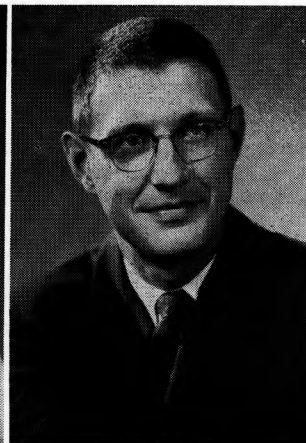
PAUL D. SIMKINS has joined the staff of the Department of Geography as assistant professor. Mr. Simkins received his A.B. and M.A. from the University of Missouri in 1951 and 1954, respectively, and expects to receive his Ph.D. from the University of Wisconsin in December of this year. He has published several articles on the subject of his Ph.D. thesis, "Regionalisms in the Recent Migration to Arizona." Mr. Simkins' specialty is in the field of population geography. He spent two years in the United States Navy from 1946-48. He is a member of the Association of American Geographers.

WILLIAM O. WILLIAMSON, a native of Luton, England, has joined the staff of the Department of Ceramic Technology as associate professor. Dr. Williamson has received several degrees from the University of London—the B.Sc. in both chemistry and geology and the Ph.D. in geology in 1933. In 1958 he returned to the University to obtain the D.Sc. in geology and industrial chemistry. Dr. Williamson has been engaged in ceramic research, consulting, and

in excess of its current needs. The productivity of the American coal mines has jumped upwards in recent years while productivity in German, Polish, and British mines has advanced very little. As a result, 70 per cent of the coal imported into Germany in 1958 came from the United States. Early in 1959, West Germany



Williamson



Simkins

teaching in Britain, South Africa, and Australia. Prior to coming to Penn State, he was principal research officer for the Commonwealth Scientific and Industrial Research Organization in Australia. He is a member of the British Ceramic Society, Mineralogical Society, Geologists' Association of London, Geological Society of Australia, and is a Fellow of the Institute of Ceramics and of the Royal Institute of Chemistry in Great Britain. His particular field of research is in petrology, mineralogy, artificial deformation of clays and its effects on properties and micro-structure, refractories technology, rheology of organic melts and micro-structure of crystallized melts.

United States would concentrate on those products which it produces cheapest and best, the value derived from exports could exceed the cost of those products it would be forced to import. Under these circumstances the nation as a whole would remain economically stable and the standard of living would rise even though some individual industries would be hurt. If, on the other hand, the United States would find itself losing the competitive battle, it would mean a declining standard of living accompanied by economic and social stress.

The protectionist policy is by far the safer course to follow because it eliminates the risk of losing domestic markets to foreign goods and the drain of an unfavorable balance of trade. At the same time, it accepts as inevitable a probable slow decline in the standard of living due to a gradual increase in the cost of domestic resources and manufactures. No matter which policy is adopted, high-cost labor which can not be justified in terms of productivity and/or skill works to the disadvantage of the nation. In a protected economy, it means less per dollar spent. Under free trade it means a loss of markets, jobs, and income.

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ucts with the domestic industry protected by government import quotas.

In contrast, the American coal industry of 1941 was not a major exporter. Though the United States coal miner was more productive than his foreign counterpart, the difference was insufficient to compensate for the lower wages, government subsidies, and better location of the coal mines in the United Kingdom, Germany, and Poland. Today, the United States is the largest exporter of coal in the world because it is one of the few nations which still possesses reserves of high-grade, low-cost coal

was forced to impose a tariff on coal imported from outside the Coal and Steel Community.

Implications for the Future

If the United States continues to lose ground with respect to cost, quality, and technologic superiority, it will have to make a decision on whether to pursue a protectionist policy with a somewhat lower standard of living for its population or to enter into free international competition with the attendant risks. The latter course would be especially difficult for the United States mining industry. However, if the

Wanted

The Pennsylvania State University has an administrative staff opening in Continuing Education for a ferrous metallurgist with production experience. Responsibilities include the organization of technical classes and supervision of metallurgical education program but does not include teaching. Some travel. Write, Mineral Industries Continuing Education, 102 Mineral Sciences Building, The Pennsylvania State University, University Park, Pennsylvania, giving education and vocational background.