leagues have made numerical computations on the behavior of a hurricane with seeding. Despite the approximations involved, the development of the velocity distribution in the storm as observed by aircraft traversing the hurricane and as predicted by the computer was remarkably similar, not only in shape but also in magnitude (*6*). The impact of such information is discussed in (*7*).

But even if the facts are better known they do not define the responsibilities of the decision-maker and his liability to those who think that his actions have increased their exposure to danger. The problem of dealing with claimants is compounded by the forecaster's limited ability to predict the track and intensity of a hurricane 12 to 15 hours in advance. When a hurricane comes ashore, it may spawn a few small tornadoes with localized winds much higher than those predicted by the forecaster. With the limitations on achievable instrumentation and the necessity to warn the public in simple terms, the forecast must appear incorrect (one way or another) to many observers. No forecaster can appear to be infallible to a majority of those affected, even if he has skills no forecaster now possesses.

Clearly, legislation should be drawn up to clarify the responsibilities of the decision-makers. One proposal is that legislation establish a decision board empowered to decide on each hurricane threat. This decision board could be legally freed of liability from public suits by congressional enactment, provided the board acted in accordance with provisions established in conjunction with the elected representatives of the regions likely to be affected by the hurricane. For example, the legislature or the governor of the State of Florida could appoint a committee which would meet with the hurricane decision board and agree to the rules that would be used in deciding whether a hurricane should be seeded when it threatened that state. When a hurricane approached the Florida coastline, the decision board could then be summoned to give an on-the-spot decision. There would also have to be compacts between neighboring states to take into account hurricanes that approach or cross state borders. The entire process would have to be supervised by the federal government since it would involve compacts among the states and would involve the use of federal facilities.

Whatever the final form of appropriate legislation, its development will require the participation of representatives of many disciplines and many interests. It is hoped that through the decision analysis format the discussions can be carried forward in a rational manner. If this should prove to be the case, we will have witnessed the beginning of a new approach to the treatment of problems involving technology and society.

MYRON TRIBUS

Xerox Corporation,
Rochester, New York 14603

References

1. R. A. Howard, J. E. Matheson, D. W. North, *Science* **176**, 1191 (1972).
2. M. Tribus, *Rational Descriptions, Decisions and Designs* (Pergamon, New York, 1969).
3. "Guidelines for the practice of operations research," *Oper. Res.* **19** (No. 5) (1971).
4. R. H. Simpson and J. S. Malus, *Sci. Amer.* **24** (No. 6), 27 (1964).
5. S. L. Rosenthal, *ESSA Tech. ERL TM-NHRL 88* (January 1970).
6. H. F. Hawkins, *Mon. Weather Rev.* **99**, 427 (1971).
7. M. Tribus, *Science* **168**, 201 (1970).

20 June 1972

The Thermodynamics of Gases Dissolved at Great Depths

In a recent report (*1*) Fenn calculated the equilibrium partial pressure of dissolved gases in water at great depths, and he requested a thermodynamic derivation and a physical explanation of the exponential equation he employed. It is my purpose in this technical comment to demonstrate the derivation of a rigorous expression for gas solubility at high hydrostatic pressures, and to give a physical interpretation of its form in terms of molecular thermodynamics.

The basis for such a derivation is the proper definition of the reference state in Henry's law, leading to the derivation of the classical Krichevsky-Kasarnovsky equation (*2*). Instead of partial pressure, it is more general to work in terms of the fugacity f (*3*), stating Henry's law as (*4*)

$$\ln \frac{f_2}{x_2} = \ln H_{2,1} + \frac{\bar{v}_2^{\infty}(P - P^0)}{RT} \quad (1)$$

where the subscript 2 refers to the solute and the subscript 1 refers to the solvent, x is the mole fraction, $H_{2,1}$ is the constant of Henry's law, and R is the gas constant. The reference state conditions for $H_{2,1}$ must be defined exactly, and these are taken to be infinite dilution of solute in solvent at the temperature T and at some reference pressure P^0. Normally P^0 is chosen (for convenience) as a pressure of either 1 atm or zero, or as the solvent vapor pressure.

The final term in Eq. 1 is the Poynting correction, which takes into account the fact that even isothermal pressure changes alter the reference condition, and a correction term must be added. The change in fugacity due to an isothermal variation in pressure is given in terms of the change of Gibbs energy Δg as

$$RT \ln \frac{f_2}{f_2^0} = \Delta g = \int_{P^0}^{P} \bar{v}_2 dP \quad (2)$$

where f_2 is the fugacity of the solute at pressure P and f_2^0 is the fugacity at the reference pressure P^0. Also $\bar{v}_2$ is the partial molal volume of the solute in solvent, and at the reference composition this is taken as the infinite dilution value, $\bar{v}_2^{\infty}$. Normally, this quantity $\bar{v}_2^{\infty}$ is assumed to be independent of pressure; this assumption is quite justifiable for solutions in the relatively incompressible solvent water, up to pressures of the order of about 1 kb, the maximum ocean pressure encountered.

The isothermal variation of fugacity in a potential field can be shown to be (*5*)

$$f_2 = f_2^0 \exp\left(\frac{Mgd}{RT}\right) \quad (3)$$

where M is the molecular weight of the solute, and the pressure varies with depth d in terms of the density ρ of seawater

$$P = P^0 + \rho g d \quad (4)$$

where we assume for convenience that the surface pressure P^0 is taken as the reference pressure. If we further assume that the ideal gas law is a good approximation for the fugacity of the solute gas at the low surface pressure P^0, then combination of Eqs. 1 to 4 results in the expression

$$x_2 = \frac{P^0}{H_{2,1}} \exp\left[\frac{(M - \rho\bar{v}_2^{\infty})gd}{RT}\right] \quad (5)$$

This exponential result is equivalent to Fenn's equation 1, and, as he showed, since M (32 for O_2) is very close to the product of the seawater density ($\rho = 1.023$ g/cm^3) and the partial molal volume of O_2 ($\bar{v}_2^{\infty} = 32$ cm^3/mole), the variation of O_2 concentration with depth is slight, although significant differences are predicted for other gases.

For a physical understanding of the meaning of Eq. 5 one must recognize that the exponential term consists of terms for two counteracting effects. First, the term *Mgd* corresponds to the increased potential due to a body force (gravity) at greater depths; this is quite equivalent to Fenn's barometric-column, and this means that in the gas phase (the barometric column) fugacity rises exponentially with depth because of the increasing weight of a column of gas. Second, there is a gravitational effect on the fugacity of the dissolved gas in the liquid due to the Poynting effect. This term accounts for the increased isothermal work (or Gibbs energy) needed to force a solute molecule into solution at elevated pressures, and the partial pressure, or fugacity, is the exponential of the chemical potential, which is no more than a partial molal Gibbs energy. In other words, the increased pressure augments the "escaping tendency" of the gas, such that at a depth of 10 km, despite the fact that the solubility of O_2 is essentially constant, the partial pressure is several times higher than that at the surface.

Note added in proof: A similar response to Fenn's report (*6*) was published while this technical comment was in press. Andrews has used a somewhat different approach to arrive at essentially the same result as here; moreover, he has shown an extension of the same treatment to a model of the distribution of radioactive heat sources in the earth's crust.

CHARLES A. ECKERT
Department of Chemical Engineering, School of Chemical Sciences, University of Illinois, Urbana 61801

References and Notes

1. W. O. Fenn, *Science* **176**, 1011 (1972).
2. I. R. Krichevsky and J. S. Kasarnovsky, *J. Amer. Chem. Soc.* **57**, 2168 (1935).
3. The fugacity is a property defined by G. N. Lewis to have units of pressure and to be the exponential of the better known chemical potential μ, such that for any isothermal change

$$\Delta f_i = \exp \frac{\Delta \mu_i}{RT}$$

The fugacity has the useful property of becoming equivalent to the partial pressure in the limit of low pressure (ideal gases).
4. A more detailed derivation is given in J. M. Prausnitz, *Molecular Thermodynamics of Fluid-Phase Equilibria* (Prentice-Hall, Englewood Cliffs, N.J., 1969), chap. 8.
5. K. Denbigh, *The Principles of Chemical Equilibrium* (Cambridge Univ. Press, London, ed. 2, 1966).
6. F. C. Andrews, *Science* **178**, 1199 (1972).
7. Supported by National Science Foundation.

21 August 1972; revised 21 December 1972

Cell Repository

The National Institute of General Medical Sciences (NIGMS) has been supporting a research program on genetics with special emphasis on genetic disease, and has now awarded a contract to the Institute for Medical Research, Camden, New Jersey, to establish and operate a repository of genetic mutant cell cultures and normal control cultures stored in liquid nitrogen to facilitate and support expanded clinical and basic research programs in this field.

A scientific advisory committee (F. H. Ruddle, chairman; R. Krooth; S. Gartler; K. Hirschhorn; W. Mellman; E. Neufeld; and G. Sato) has been instrumental in coordinating the development and research aspects of the repository. The committee will have the functions of (i) recommending matters of general policy and (ii) recommending specific policies, such as the inclusion of particular cell lines or classes of cells.

The repository will contain viable cells in low passage with single and multiple gene defects, both defined and undefined at the molecular level; chromosome abnormalities (translocations, deletions, and others); polymorphisms (isozymes, antigens) plus carrier and normal control cultures. Most lines will be of human origin, but a limited number of nonhuman mammalian lines with unique or valuable genetic characteristics may be accepted.

The initial phase of this program is to establish cell cultures from patients in which the genetic abnormalities have been confirmed. Additions to the collection can be in the form of low passage cell cultures, or, preferably, skin biopsies from patients with confirmed genetic variant diseases. Initiating cell cultures from biopsies assures preservation in low passage to provide confidence that they will retain the in vivo karyotype, metabolic, and enzyme characteristics and, at the same time, have maximum life-span in culture and minimum opportunity to become contaminated during passage. All cultures are grown without antibiotics after primary culture, and stored in liquid nitrogen. Minimum criteria of cell cultures accepted in the repository will be freedom from contamination with bacteria, fungi, and mycoplasma; species of origin; karyotype; and specialized assays when applicable.

Although the emphasis during the first year will be on fibroblast cultures, the repository will accept lymphocyte and amnion cultures for storage. The advisory committee is now evaluating a number of technical problems such as biohazard regulations and clinical usefulness before suggesting the procedures to be followed in storing and shipping lymphocyte cultures.

The advantage of a central repository of mutant and normal cell cultures for genetic and biochemical studies are:

1) The study of cells from a number of persons with the same inherited disorder may reveal subtle variations in the underlying defect that would be important to its diagnosis and treatment.

2) Use of identical cell lines for study in different laboratories should facilitate the comparison of data and interpretation of research results.

3) Cell lines from some rare diseases otherwise would not be readily available to all interested investigators.

4) Investigators in different laboratories can develop and maintain numerous cell lines.

5) The availability of the skills for characterization and identification of genetic mutant cells will assure uniformity and reliability of cells from the repository.

Interested investigators are invited to utilize the repository as a source of genetic mutant cell cultures. A moderate fee will be charged plus shipping costs.

LEWIS L. CORIELL
Genetic Mutant Cell Repository, Institute for Medical Research, Copewood and Davis Streets, Camden, New Jersey 08103