Self-heated Hay.

(1) Respiration takes place causing the initial rise in temperature. The amount of respiration depends on the extent to which the plant cells have been killed in the drying process.

(2) Micro-organisms develop rapidly in the presence of moisture and with the rise in temperature, attacking the cell sap constituents and initiating decomposition.

(3) Rise in temperature up to *c.* 40° C. kills plant cells and respiration ceases. Some thermophilic micro-organisms may continue to be active above 40° C. Sufficient water and air are present to allow growth to continue. Breakdown of carbohydrates produces unsaturated compounds which are oxidized and partly hydrolysed with the production of heat.

(4) At temperatures above 40° C. the micro-organisms are gradually killed off by the temperature. *The decomposition products are then sufficient in amount to catalyse further decomposition of carbohydrates.* The increased temperature gives a greatly increased rate of oxidation of unsaturated compounds, as shown experimentally for unsaturated fatty oils.

(5) At 100° water is driven off from the heating centre, and oxidation and hydrolysis are replaced by oxidation with production of more heat. The limiting factor now is the amount of air present.

(6) The rate of chemical reaction increases sharply until the surrounding hay is charred and access to air is gained. Here, the plentiful supply of oxygen gives heat which cannot be conducted away, and ignition occurs.

Ordinary Hay.

(1) Some respiration takes place causing rise in temperature, the extent depending, as with self-heated hay, on the extent to which the plant cells have been killed in the drying process.

(2) Micro-organisms develop with rise in temperature, attacking cell constituents. Decomposition is slight, *the growth of the organisms being limited by the lack of water.*

(3) Decomposition is insufficient to set up the autocatalytic reactions, and the stack cools off.

Silage.

(1) Respiration takes place until all oxygen is used up or replaced by carbon dioxide.

(2) Micro-organisms develop and operate in the absence of air. The limiting factor here is the lack of air, and the interior of the silo cools off. Breakdown products of carbohydrates are produced; but there is insufficient air for any extensive oxidation to take place, and the heat developed is small in comparison with wet hay.

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THE CULTIVATION OF A THERMODYNAMIC OUTLOOK

THE place of thermodynamics in education was recently discussed by the Low-Temperature Group of the Physical Society. In outlining the purpose of the discussion, the chairman, Sir Alfred Egerton, explained that a feeling exists among members of the Group that the thermodynamics teaching given to students in Great Britain is often inadequate; and it was in the hope of formulating constructive proposals for its improvement that this meeting was called. He added that it was not his intention to confine discussion only to low-temperature aspects of thermodynamics, but to encourage discussion over the whole thermodynamic field.

Opening the discussion, Sir Charles Darwin pointed out the difference between the teaching of mechanics and of thermodynamics in Britain. On one hand, in the teaching of mechanics, the student is drilled to solve numerous examples until all the implications of Newton's Laws have been driven home. On the other hand, thermodynamics is often introduced in abstract terms and clothed in a maze of algebraic symbols, thereby leaving the student confused in his conception of the subject and ill-equipped to apply such thermodynamic knowledge as he has gained to new problems. Sir Charles thinks thermodynamics is a harder subject than mechanics, but not much harder.

Elementary teaching of thermodynamics in the past has been confined almost entirely to gases and liquids, and this has tended to obscure the generality of the subject. Also in setting examination questions too much demand has been made for the mathematical manipulations involved in getting, for example, from C_p to C_v. Now that the new fields of magnetism and the elasticity of rubber have been opened, other examples are available, and the teaching of thermodynamics can be widened in its outlook. Exercises in spotting the fallacies in perpetual motion machines also provide a useful field of instruction. The use of numerical examples should be extended, for only so can experience be gained of the relative importance of the various factors in a process.

In conclusion, Sir Charles Darwin posed three questions, to which he supplied his own tentative answers:

(1) Should thermodynamics play a greater part in education?

(2) At what stage, school or university, should it begin?

(3) Should statistical theory come in?

To the first question he gave an affirmative answer. In answer to the second question he considers that a start should be made at school about two years after mechanics, but to be suitable for schools the text-books will need to be re-shaped. Regarding the third question, he favours withholding statistical theory, except for a few descriptive examples which call for no mathematics.

The next speaker, Prof. E. A. Guggenheim, stated his convictions that the number of people in the world who thoroughly understand thermodynamics in all its aspects is well under a hundred, and the number in Great Britain is certainly in single figures. He said, however, that he is less disturbed by these small numbers than by the degree of ignorance of thermodynamics by the remainder of physicists, chemists and engineers. Unfortunately, this includes people whose task it is to teach thermodynamics and to abstract papers on this subject. A symptom and, at the same time, a cause of this state of affairs is the failure to afford to thermodynamics its true significance and status by confusing it with the experimental techniques of thermometry and calorimetry, and the largely empirical laws of heat transfer, under the general title of 'Heat'.

Thermodynamics, he said, has a bearing on almost every branch of physics and particularly on mechanics, hydrodynamics, electrostatics, capillarity and chemistry. In these subjects many of the laws and formulæ taught are defined only under the condition of constant temperature—for example, Hooke's Law, Ohm's Law and Boyle's Law. As soon as one inquires into the effects of varying the temperature, one enters the domain of thermodynamics. This has led to much confusion in the use of the word 'energy' in such expressions as the 'energy of a coiled spring', or the 'energy of a charged condenser'. Here the quantity cited is usually the free energy, and the total energy is a more complicated quantity, since it is to be noticed that the performance of work at constant temperature is, in general, accompanied by a simultaneous absorption or emission of heat.

Prof. Guggenheim recommended that students, immediately after learning mechanics, should be made familiar with :

(1) the existence of temperature ;
(2) the conservation of energy ;
(3) the correct definition of heat ; and
(4) the distinction between actual and reversible processes.

The quantitative relationships between work and heat can best be introduced in particular examples, such as coiled springs, compressed fluids and charged condensers, as these subjects in turn come up. Only at a later stage is it necessary to stress that all such relations are particular examples of the general laws of thermodynamics.

Prof. D. M. Newitt, speaking of the bearing of thermodynamics on chemical engineering, stated that the aim of chemical engineering is to co-ordinate a series of elementary physical operations and chemical processes in such a way as to bring about economically some desired change of state or composition in a given system. It therefore requires equally a knowledge of thermodynamics and molecular physics. He considers it desirable that the teaching of statistical mechanics and the kinetic theory should run parallel with and not follow a course in thermodynamics since, in general, chemical engineering problems are concerned not only with the driving force necessary to bring about a specified change, but also with the rate at which that change can be made to take place.

Attention was directed by Prof. Newitt to the present unfortunate divergence, both of approach and of emphasis, in the teaching of thermodynamics to physical chemists on one hand, and engineers on the other. Thus the chemical engineer, who receives tuition in both schools, is liable to unnecessary confusion. The wide variation of notation between different text-books of both subjects has also added to the confusion. Prof. Newitt voiced the plea that uniformity of notation should be adopted in the teaching of thermodynamics. In conclusion, he suggested that more use might be made of graphical and geometrical representation in the teaching of thermodynamics. Exercises in the construction of such diagrams and models might well make up for the paucity of laboratory experiments for illustrating thermodynamic principles.

Mr. A. M. Clark said that, although a complete knowledge of thermodynamics may be restricted to a few, an understanding of the principles involved is important for all scientific workers, irrespective of the particular branch of the subject chosen for specialization. He considers that the first and second laws of thermodynamics are even more fundamental and more rigid than the basic laws of chemistry and mechanics, such as the laws of conservation of mass and Newton's Laws of Motion. The student should be introduced to them at the earliest possible stage, that is to say, at the same time as he learns to appreciate the other fundamental laws. For this purpose the early teaching of thermodynamics should be divested of advanced mathematics and complex nomenclature. Illustrations of the principles of irreversibility can be found in many simple processes. Yet fallacies are often encountered in scientific papers published in reputable journals, showing that these principles are imperfectly understood, even by some who aim at instructing others.

The next speaker, Prof. F. E. Simon, advocated that the first introduction to thermodynamics should be at school ; only so would the second law be quickly mastered. Moreover, this should be done even if it necessitates sacrificing some of the more tedious parts of physics. He lamented the present inadequacy of elementary thermodynamic text-books, and while commending Ewing's book, he considers the engineer's approach far too restricted. In teaching thermodynamics he considers the use of complicated systems and involved mathematical derivations inadvisable. The main difficulty experienced by students is in grasping the fundamental ideas implied by the thermodynamic laws, and the best way of elucidating them is by the use of numerous examples. In this connexion he considers the heat pump as one of the best illustrations for bringing home to students the significance of the second law.

Speaking as a physical chemist, Mr. C. R. Bury claimed that the modern precise thermodynamics is of little use in meeting practical problems. The work of Van t' Hoff gave us a method that is easy to apply, but the answer is unreliable. The modern thermodynamics is only useful with very simple systems, and as soon as a problem occurs requiring high pressures, mixtures, or solutions, the information is so scanty that the methods are useless.

Dr. K. Mendelssohn emphasized that in teaching thermodynamics the primary need is to explain what the subject is about and not to plunge into a mass of symbols. A study of the phenomena occurring at the transition from the superconductive to the non-superconductive state affords useful instruction.

Dr. M. Ruhemann disagreed with Sir Charles Darwin that Newton's laws are more readily understood than the laws of thermodynamics. He personally has found Newton's second law more difficult to understand than the second law of thermodynamics. He agreed with other speakers that thermodynamics should be introduced at school, and he considers that by embodying it in examples such as internal combustion engines and fuels it could be made interesting to these ages. He commended warmly the text-book by Boznjaković and expressed regret that it is not available in English.

Dr. N. Kurti directed attention to the fact that in many universities there are several parallel and simultaneous courses in thermodynamics for chemists, physicists and engineers. If, instead, a combined course of lectures was given with emphasis on the nature and scope of the subject, considerable benefit would result. Mr. J. H. Awbery added to Dr. Ruhemann's contention, that the laws of thermodynamics are no more difficult than those of Newton, the point that students at school are drilled in mechanics at an age before they can ask questions, and it is solely this discipline which makes mechanics seem far easier. If thermodynamics was hammered home at an early age with plenty of illustrations, the concept of free energy would be as easy to understand as volume or temperature. Dr. L. R. G. Treloar also agreed with this point, stating that thermodynamics should be taught as dogma. Only so will familiarity and confidence be attained.

Summarizing the discussion, Sir Alfred Egerton indicated several points on which agreement had been reached. First, elementary instruction in thermodynamics should be given at school, and for this a very carefully prepared syllabus would be required. Secondly, in teaching thermodynamics more use should be made of diagrams and solid models; and thirdly, a unified system of notation is desirable. In conclusion, he pointed out that in 1850 Clausius and Kelvin had simultaneously, though independently, formulated the Second Law of Thermodynamics, and he expressed the hope that in 1950 the centenary would be suitably celebrated.

G. G. HASELDEN

NATURAL SCIENCE AND THE FINE ARTS*

By F. IAN G. RAWLINS

Scientific Adviser, National Gallery

I PROPOSE to consider here the relations which we may expect to find existing between these two great examples of human endeavour. In so doing it will be seen that the man of science, using that term in the broad sense, has been instrumental both in the fashioning of objects of art and in caring for them afterwards. It appears likely that many of the great masters of classical art were somewhat casual in their concern, as judged by our standards, for the beautiful things which they made; nowadays conservation has become an art in itself, and the philosophers are not slow in pointing out that our preoccupation with the treasures of the past may be bound up with a certain lack of confidence in ourselves to generate loveliness in our own time. However that may be, there is much to be said for a close study of the techniques of the great masters, and such a discipline does, in fact, help us to devise ways and means of looking after our heritage more adequately.

Thus, the man of science needs to be something of a *Kunstforscher* as well as competent to apply any method or methods which will help forward objective investigations of structure and condition. Clearly, one should know a good deal about materials and their limitations, above all to be imbued through and through with a sense of 'safety first', if museums and galleries are to reap positive advantages from the possession of a laboratory and its equipment. The war years, too, have provided problems on a scale commonly associated with those in engineering.

The greater part of this discourse will be devoted to the physics of classical paintings, chiefly because I find myself rather less incompetent perhaps with them than with other material; and secondly on the score of their combined weight and fragility, which makes them probably the most intractable of all. From the technical point of view they fascinate, not merely artistically, but because they are frequently so 'awkward'. At the National Gallery, for example, we have pictures weighing anything from a few ounces to nearly three quarters of a ton. To design plant both convenient and safe for such a range is not too easy. In surface area as well there is wide variation, from about 20 square inches to 16,000 square inches. The apparatus in question consists essentially of X-ray, ultra-violet and infra-red sources of radiation, with appropriate recording gear, both photographic and visual. In addition, there is considerable scope for colorimetry and for microscopy in polarized light. Further, the orthodox methods of photography have been extended to include macrographs, the use of special filtration processes, and the employment of raking light. In all this, one is not looking for the production of something that looks like the picture; we are seeking information which, in general, can only be obtained in bits and pieces, here a little and there a little, by deliberate exaggeration or suppression as the case may be. It is only when a purposeful effort at integration is made that the significance of these separate approaches becomes apparent. No method is known which by itself will tell us all that we wish to know, and unfortunately there are many examples in which failure occurs in spite of everything.

Here perhaps is the place to emphasize that scientific practice and methodology will never be substitutes for stylistic knowledge and insight. A certain amount of harm has occasionally been done to the cause of laboratory co-operation by expecting it to achieve results of which it is *a priori* incapable. Nevertheless, its help in confirmation, and briefly, in lifting conclusions out of the region of subjective judgment, has been demonstrated time and again. This only amounts to asserting the obvious truth that the nature of evidence needs extremely careful thought when using such evidence under conditions wherein the original assumptions cannot well possess full formal validity. Maybe this is why, in matters of this kind, there has been much reasoning by analogy, that is, from particular to particular. Scientific method will strive to raise this one degree in the hierarchy by attempting to apply the process of induction (that is, reasoning from the particular to the general); so far as one can see, it seems most unlikely that the final, or deductive, system will ever be reached in scholarship of the type we are contemplating now, since argument from the general to the particular is almost a denial of the individualism of art. It is a fact, however, that a remarkable degree of agreement is often registered among people thoroughly conversant with questions of style, iconography and provenance, but this is not to say that objective testing has no place in these deliberations. Its verdict *may* be crucial.

My purpose thus far in sketching, necessarily briefly, the theoretical background of the scientific-artistic complex has been to try to elucidate certain basic suppositions which experience shows to be liable to misapprehension or even to neglect. It is

* Substance of a Friday evening discourse delivered at the Royal Institution on February 14.