as usual, continues an air-passage to the pharynx, opening at the back of the hard palate by a median orifice in common with its fellow. In sizable skulls, as of a raven, hawk, or eagle, a bristle or even a wooden toothpick readily traverses the conduit which runs between the basisphenoid and the underlying basi-temporal. This whole passageway, from outer ear to tympanic cavity, and thence through eustachian tube to pharynx, represents the persistently patulous part of the first post-oral visceral cleft of the embryo, only occluded by the membrana tympani. Near the eustachian orifice are observed two definite openings. The anterior and superior of these is the fenestra ovalis, fitted, as usual, with the foot of the stapes, as seen in fig. 1, closed by membrane, which further occludes this opening into the *vestibular* cavity. The other is the fenestra rotunda, similarly leading into the *cochlear* cavity. The two are generally close together, separated merely by a bony bridge or bar. The former lies always in the obliterated suture between the proötic and opisthotic elements of the petrosal bone, the latter wholly in the opisthotic; both are thus as in man. Close examination at a point somewhere about the fenestra ovalis will discover a minute foramen, corresponding to the human 'stylo-mastoid foramen' inasmuch as it represents the orifice of exit of the seventh cranial nerve ('portio dura') from the petrosal bone, here in the cavity of the middle ear, there being none such upon the outside of the skull. Thus, in the dry skull of a bird, the hard parts of the tympanic cavity, including the eustachian tube, can readily be inspected from the outside; even the limits of the proötic and opisthotic bones can be determined by the site of the fenestra ovalis, and the ossicula auditus be seen *in situ*. To see these things in the human or any ordinary mammalian ear, requires special preparations, as they lie in a tympanum which is itself at the bottom of a contracted tube. Details of mere size and shape aside, the above general description of the passageways will apply pretty well to any bird, and should suffice for recognition of the parts; though the number and variety of the irregular pneumatic openings (comparable to those of the human mastoid cells) may be puzzling at first sight.

*(To be continued.)*

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## *ON THE KINETIC THEORY OF THE SPECIFIC HEAT OF SOLIDS.*

IN a paper entitled 'Kinetic considerations as to the nature of the atomic motions which probably originate radiations,' [1] the writer has given reasons in support of the hypothesis that different chemical atoms are all composed of the same kind of ultimate atoms, which are in every respect equal and similar. Reasons were also given, tending to show that the vibrations of these ultimate atoms originate luminiferous and thermal radiations. And further, supposing radiations to originate in the vibrations of equal and similar ultimate atoms which are set in vibration by the collision of moving molecules, an attempt was made to prove that two unlike masses of gas which are in thermal equilibrium by radiation will also be so when mixed; i.e., when the equilibrium depends upon the collisions of the molecules rather than upon radiation.

The object of the present paper is to consider the probable physical state of solid bodies, especially as to the amount of energy distributed among the different degrees of freedom possible in such bodies, and to show that the same hypothesis of equal ultimate atoms would cause solids which are in thermal equilibrium by radiation to be also in thermal equilibrium when brought into contact, i.e., when the equilibrium depends upon the collisions of the molecules.

Let us notice, in the first place, what is apparently the mechanical significance of Dulong and Petit's law, which may be stated thus: the amount of heat which must be imparted to a chemical atom of a simple solid body to increase its temperature one degree is approximately the same for all the elements. Neumann has further shown, that, for compound solids, those of similar chemical composition require approximately the same amount of heat per chemical atom, but the amount is less than for simple solids. There are, however, a very few unexplained exceptions to these laws, which are due possibly to uncertainty as to atomic weights.

The mechanical explanation of these experimental laws seems to be contained in the statement, that, in simple solids, cohesion and chemism are one and indistinguishable; or, to express it otherwise, we may say that the molecules of simple solids are monatomic, the cohesion being, of course, much greater in some solids than in others.

That this is a correct conception of the relations of the atoms of a simple solid, is made probable by various facts, among which this may be mentioned, — mercury and cadmium, which are known to be monatomic as gases, as solids fulfil Dulong and Petit's law, and are therefore in the same physico-chemical state

[1] SCIENCE, ii. 76.

as other simple solids. Another fact is that already mentioned, viz., the specific heat of compound solids per atom is less than that of simple solids; and to this it may be added, that the specific heat of simple solids is less when the volume is made smaller by hammering, compression, or cooling, which facts will be considered more at length later.

It is shown in the kinetic theory of gases, that, when molecules of unlike gases are mixed, the mean progressive energy of each molecule is the same, whatever its weight.

Now, when a gas is in contact with a solid, will the collisions of the gaseous molecules with those of the solid cause the latter to have the same mean progressive energy of vibration as those of the gas? That will depend largely upon the duration of the collision. If the time occupied by a collision is so brief that only a small portion of a vibration of the solid molecule is described during the collision, then the laws of impulsive forces may be applied, according to which the effect of the finite forces acting during the interval may be neglected.

In case the collision is brief, the distribution of the mean kinetic energy between the molecules of the gas and solid will be very nearly the same as between different gases, and the mean kinetic energy of a simple solid molecule will differ little from that of a gas at the same temperature.

In cases, however, in which the modulus of elasticity of the solids considered is so great as to make the period of vibration of the molecules also brief, their mean kinetic energy would be materially smaller than in the previous case; and, if a solid could be found whose molecules were immovably fixed, no vibratory energy whatever could be imparted to its molecules.

Now, Dulong and Petit's law seems to show that all simple solids, even those having the highest modulus of elasticity, have an elasticity so small, compared with that brought into action between molecules at the instant of free collision, that the distribution of kinetic energy is approximately the same as if the body were gaseous and monatomic. But since the laws of perfect elasticity require that the mean potential energy shall be equal to the kinetic, it follows that the specific heat of a simple solid should be approximately twice that of a monatomic gas at the same temperature and of the same atomic weight.

The actual specific heats of mercury and cadmium gas would be of great interest in this connection, were they known, even though they could only be determined at temperatures far removed from those of their solids.

The foregoing statement has been based upon the assumption that any degree of freedom which suffers partial constraint, as do the degrees of freedom of translation of a gaseous molecule when it becomes solid, will have for that reason less kinetic energy imparted to it during molecular collision. This subject has been treated somewhat at length in previous papers upon the kinetic theory; but in this connection it may be useful to make a quotation from Thomson and Tait: "If a set of material points are struck independently by impulses, each given in amount, more kinetic energy is generated if the points are perfectly free to move, each independently of all the others, than if they are connected in any way."[1]

This mechanical theorem not only has special application to the partial constraints introduced into the freedom of motion of molecules when they change from a gaseous to a solid state, but it applies, also, to the additional constraints introduced into the degrees of freedom of solid atoms when those atoms become more closely bound together by chemism into groups, i.e., into molecules. Evidently, the bonds of union between the atoms of a compound solid molecule are such that these degrees of freedom are considerably more constrained than those which unite the atoms of different molecules; so that, in compound solids, the forces of cohesion and chemism are different, and quite distinguishable the one from the other.

Now, what, according to the mechanical theorem above quoted, is the effect of introducing the additional constraints required in order to group a simple solid, or mixture of simple solids, into molecules, and thus make it a compound solid? The effect will be to diminish the mean kinetic energy of the system as derived from the impacts of the molecules of any gas surrounding it. This is, in fact, what occurs, as appears from the experimental truth previously mentioned, — that the specific heat per atom of compound solids is less than that for simple solids. How much the specific heat per atom is diminished should depend upon the intensity of the chemical attraction, which certainly must be much greater than the cohesion between atoms of simple solids, to cause such marked deviations of specific heat per atom as compound solids exhibit. This result, when combined with that arrived at in connection with the discussion of Berthelot's law, in my paper upon 'An extension of the theorem of the virial,' etc., to the effect that the heat evolved in chemical decomposition is greater

[1] *Nat. phil.*, art. 315.

the greater the attractive force, enables us to enunciate the following law, the truth of which I am at present unable to verify for want of sufficient experimental data: those solids, other things being equal, which evolve the greater amounts of heat of chemical decomposition in changing from simple mixtures to compound solids, are those which have less specific heat per atom. The phrase, 'other things being equal,' in the above statement, refers to the fact that similar compounds which are chemically similar are in strictness comparable. Many other circumstances, moreover, besides want of chemical similarity, may, in special cases, mask the experimental results; yet the truth of the law should be clearly recognizable in any general comparison of specific heats with the heat of formation of compound solids.

Similar principles evidently apply to the cases in which simple solids are permanently decreased in volume by hammering or compression; for then greater cohesive forces are brought into action, and the specific heat is diminished. It remains to be shown, in conclusion, that thermal equilibrium, which has been established by collisions of gaseous and solid molecules, will continue to exist when its continuance depends upon radiations between equal and similar ultimate atoms which are set in vibration by molecular collisions; or, to state it differently, it remains to be shown that the ultimate atoms of a gas and a solid in contact, each have the same mean vibratory energy with respect to each of their degrees of freedom with respect to each other. This appears to be a direct consequence of the laws of constrained motion which have been considered in this and previous papers. It is only necessary that the impacts of a pair of solid molecules with each other should be such as to mutually impart and receive the same mean amounts of energy as would those of a gaseous and a solid molecule at the same temperature, to cause it to be a matter of indifference whether a given solid molecule is struck by another solid molecule or by a gaseous molecule; and, when so struck, each ultimate atom will receive its proper proportion of energy, whether it form part of a solid or of a gaseous molecule.

It is my intention to return to this subject hereafter, and to treat the vibrations of ultimate atoms more at length, in the hope of being able to show, more precisely than has been done so far, how the characteristic differences in the spectra of solids and gases arise.

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## *CLIMATE IN THE CURE OF CONSUMPTION.*—I.

THE prevalence of phthisis pulmonalis is such a well-attested fact, that to adduce statistics to prove it would seem to be labor thrown away. Since the eradication of small-pox in consequence of the introduction of vaccination, phthisis heads the list as the prime cause of the large mortality. The insurance companies recognize the fact, and the statistics of the New-York mutual life-insurance company show, that between the ages of twenty and thirty years the mortality from phthisis is thirty-three per cent of the whole mortality. The U. S. census for 1870 shows that in the state of Maine the mortality from consumption was fifty per cent for the same ages.

Equally well known is the belief in climate as a cure for the disease. There are certain well-recognized climatic conditions known to be favorable to the prophylaxis and cure of the disease. This knowledge is largely empirical, based upon trial and observation; but there is, underlying it, a substratum of conviction, that is justified, on the one hand, by careful clinical observations, and, on the other, by facts ascertained by carefully conducted experiments.

The writer proposes, in the thoughts to be presented, to make these various elements his tests in searching out a desirable climate in the United States for the cure of phthisis. He offers, as his data for forming an opinion, carefully compiled tables, furnished by the Signal-service bureau, U.S.A.; and he wishes to emphasize the fact, at the outset of his remarks, that a climate may become desirable quite as much by comparison as on account of its intrinsic properties; that even though it may not possess in itself all desirable qualities, yet it may contain so many as to be, by comparison with others, the climate par excellence. With this thought in view, the writer has prepared tables embracing all the chief resorts in this country for phthisical invalids, — tables embracing a range of the whole country, from Jacksonville to St. Paul, and from Boston to Los Angeles.

He has given the data for Augusta, Ga., as the best substitute for Aiken, S.C., at which place there is no signal-station; and in doing so he thinks that he is presenting data which will fairly represent the climatic conditions of Aiken.

He wishes to gratefully acknowledge his indebtedness to the chief signal-officer, U.S.A., to the observers at each of the stations included in the tables, and especially to Sergeant F. M. Neal of the Denver station, for their kindness in furnishing him with the data from which the tables are compiled.