DISCUSSION.

The Chairman pointed out that he had found other metals besides aluminium break down in the way described by the author, for instance, manganese, when it was produced by reduction from its oxide by means of metallic calcium.

Dr. Walter Rosenhain said that the Paper was a most interesting and suggestive one, although he hardly thought that Mr. Law had justified the title of his Paper. It was true that the light alloys had not as yet fulfilled the somewhat extreme hopes which had been entertained in some quarters, but they were none the less proving distinctly useful, as for instance in their use in connection with aeronautics in preference to high-tension steel, owing to the larger scantlings which could be used when light alloys were employed.

Mr. Law had raised a number of interesting points. One of these was the property of spontaneous disintegration which was found in some alloys of aluminium. He would point out that this phenomenon was not confined to alloys of aluminium, nor even to metals—it took place in certain silicates of calcium also. In the alloys of aluminium and manganese he had tried to observe the phenomenon under the microscope and had seen the sudden ejection of minute crystals or fragments of crystals from the polished surface—it looked like a miniature volcanic eruption. Apparently it was a polymorphic change which involved an increase of volume and took place at or near the ordinary temperature.

Mr. Law had referred to the views which he and Mr. Lantsberry had expressed as to the eutectic in the aluminium-manganese series, and had suggested that it was “surely a new view of a eutectic,” apparently with the wish to suggest that the thermal arrest-points were in reality due to a transformation in the aluminium and not to the formation of a eutectic. If Mr. Law had seen the full facts as they lay before himself and Mr. Lantsberry when that statement was made, this criticism would not have been put forward. He would try and state these facts very briefly by drawing a rough sketch of the portion of the equilibrium diagram of these alloys as determined by himself and Lantsberry (Fig. 9). The liquidus curve sloped down for a very short distance from *A*, the freezing-point of pure aluminium, to a distinct eutectic point *B*, and then upwards to the point *C*, corresponding with the compound Al_3Mn . Through the point *B* passed the typical eutectic line, and there was nothing novel at all in the view that the substance freezing at *B* was a eutectic; the definition of a eutectic which he adopted was that it was the alloy of lowest freezing-point found in any series, and that the laminated structure so frequently found in these substances was an incidental and not an essential feature; if a eutectic consisted largely of one constituent, this laminated structure could not be developed, although the mode of freezing might be exactly the same as that of a eutectic in which the two constituents were present in more equal proportions. A curious feature about the Al-Mn series, however, was that the eutectic line through the point *B* appeared to be definitely double—each alloy gave two distinct arrests. Whether this lower line extended right up to pure aluminium and whether it might perhaps correspond to the transformation suggested by Mr. Law was an open question

192 FAILURE OF THE LIGHT ENGINEERING ALLOYS,

if it did, we should have the very remarkable fact that a transformation of this kind was independent of the concentration. This was unusual, although not quite unique—it implied that the product of the transformation possessed no power at all of dissolving the alloyed element (in this case Mn).

With regard to the want of sharpness in the freezing of pure aluminium, he had often seen it referred to, but he had watched the freezing of many samples of the purest aluminium with very delicate apparatus, and had only found abnormalities very rarely. Accordingly he was inclined to attribute these abnormalities when they did occur to the presence of some impurity. Aluminium intended for standardising purposes was at once rejected if it was found to show this abnormality on the ground that it was then impure.. How far the impurities in question were themselves responsible for the second arrest, or whether they merely served to accentuate or accelerate a change which in pure aluminium was too feeble or perhaps too slow to be detected, was as yet an open question, but it could be studied by observations of the

FIG. 9.

alloys of aluminium with very small quantities of other elements. At all events, it did not seem probable that a transformation which took place so very near the initial freezing-point of the metal or alloy could be utilised technically even if it were shown that the occurrence or suppression of such a change would exert any beneficial influence on the physical properties of the alloys.

Dr. R. Seligman : Mr. Law's Paper, as all Mr. Law's contributions to the subject which he has made his own, is full of interest. To me the present Paper is especially interesting because it deals with a metal with which, for better or worse, I have been intimately connected for a number of years. I must, however, commence these short remarks by criticising one of the author's first statements. He remarks that aluminium alloys have been somewhat of a failure. This is only relatively true. True it is that the totally unjustifiable promises held out to the engineering industry have in the course of time been found to be baseless, but this is the fault of the extravagance of those promises rather than of the shortcomings of the alloys. If it

FIG. 10.

is true that the proportion in which alloying metals can be profitably added to aluminium is small, it is none the less true that the effect which these small additions have on aluminium is of the utmost importance to engineers, and Mr. Law would be the last to deny that several important industries would suffer irreparable damage if they were to be deprived of these same alloys. We must not lose sight of the fact that to-day there are at least a score of foundries in England alone, and some of no mean size, which exclusively cast aluminium alloys. One more point. I am absolutely convinced that even if the number of useful alloys is not to be largely increased by research, the more exact knowledge of the existing alloys and the best conditions of their preparation, with which the work of Mr. Law and his fellow metallurgists is furnishing us, will have the effect of very largely increasing the utility of the various compounds of aluminium already in use and of widely extending their uses and fields of application. It is the lack of certainty and reliability which has been their worst enemy, and these deficiencies must be almost entirely due to lack of definite knowledge.

With regard to the disintegration of many aluminium alloys, Mr. Law's observation that it is preceded by an increase of volume is worthy of the most careful attention. Even more so is the fact which the author brings out that by chilling and by work done upon them immediately after formation the disintegration can be inhibited. This seems to open a field for very interesting and probably valuable research. That there may be further means of preventing disintegration seems at least possible. I have in my collection an iron aluminium alloy which was formed under conditions where both chilling and work were absolutely excluded. After nearly six years the crystal faces are as bright and the angles as sharp and well-defined as on the first day of their formation (Fig. 10). Mr. Law's remarks on the cooling curve of aluminium are of particular interest to me. A number of years ago I was struck by the very striking change which aluminium undergoes at a point some distance below its melting-point. In somewhat the same manner as tin, aluminium loses all tenacity and may be quite readily separated into its component crystals. The phenomenon is not, however, quite analogous to that shown by tin. It seemed to me that the cooling curve might show an irregularity at the same point, but in the absence of suitable instruments I was not able to determine this.* At the time I was also unable to find any published data on the cooling curve of aluminium. It is clear from Mr. Law's statements that the break in the curve which I expected is actually found, but whether it has any connection with the change of state to which I have referred is problematical. If Mr. Law is correct in ascribing it to impurities in the aluminium, there can be no such connection, because the purest aluminium obtainable (about 99·8 per cent.) shows the same mechanical change.

In concluding, Mr. Law gives expression to the hope that in the apparent allotropy of aluminium a new and fruitful field of work may be discovered. My hopes of this are not high. Moreover, I should feel that we had suffered a distinct loss if the attention of metallurgists were devoted to this subject *at the present moment*. I feel that, as one intimately connected with the aluminium industry in all its aspects, I cannot too often or too urgently insist that what is immediately wanted is definite, authoritative, and reliable information as to the methods of preparation and properties of the alloys already in common use.

* Dr. Harker, to whom I referred the matter, was not able to get entirely satisfactory results, although he gave me to understand that he found indications of the point I anticipated.

Dr. J. A. Harker said he had experimented with the samples of pure aluminium given him by Dr. Seligman some time ago, specially with a view to determine whether on the cooling curve any indication could be obtained of the point, at about 630°C ., where the material on heating reaches a pasty stage. Dr. Seligman had told him that at this temperature a lump of aluminium when hit with a hammer breaks up somewhat like dry cheese, and it seemed interesting to see if this change was accompanied by any thermal phenomenon. He had found only very uncertain indications of any discontinuity. The experiments themselves were nevertheless perhaps worth describing briefly. Owing to the very rapid attack of the usual type of porcelain protector tube by aluminium, the latter is rendered impure very quickly. For these experiments therefore cylindrical graphite crucibles, about 1 in. to $1\frac{1}{4}$ in. internal diameter and $3\frac{1}{2}$ in. to 4 in. long were employed, and the porcelain thermo-couple protector tube was replaced by one turned from a rod of graphite. The walls were left very thin for the lowest two inches of the tube. This arrangement proved very satisfactory. Using this comparatively deep type of crucible, it was possible, notwithstanding the low latent heat of fusion of aluminium, to get a good halt at freezing.

FIG. 11.

FIG. 12.

Mr. E. Ristori asked whether the author had tried putting mechanical work into spontaneously decomposable alloys as soon as they were cast, and if so, what the effect had been.

Mr. W. H. Merrett said he had heard Mr. Law's very valuable paper on aluminium with great interest. Unfortunately, he had no knowledge of its contents prior to the meeting, and he, therefore, had not been able to give the theories put forward any serious consideration, but he felt there was a large amount of evidence in favour of the existence of allotropic forms of the metal.

Much had been said about the peculiar cooling curves obtained with commercial aluminium, and, as long ago as 1895, the curves taken in the Research Laboratory of the Royal Mint showed these eccentricities. Although every precaution was taken to obtain accurate records of the cooling, the curves obtained from the commercial metal almost invariably resembled Fig. 12 rather than Fig. 11, and there was, in fact, always a considerable fall in temperature during the latter portion of the solidification.

Dr. Stansfield investigated this matter and found that the commercial metal produced at that time, nevertheless, had a constant initial solidification point, indicated at A (Fig. 12), of 649°C ., although the rest of the solidification varied

PARTICULARLY THE ALUMINIUM ALLOYS 195

considerably with different samples. It is hardly surprising that this rapid fall of temperature during solidification occurs when impurities are present, when we consider the fact that the addition of so small an amount as 2.5 per cent. of gold to aluminium will reduce the melting-point from $1063^{\circ}\text{C}.$ to $525^{\circ}\text{C}.$

During 1896 and 1897 the speaker obtained some remarkable curves from certain alloys of aluminium, which have, however, never been published. One of considerable interest, which is shown in Fig. 13, is of an alloy containing about 18 per cent. of aluminium and 82 per cent. of antimony.

The actual solidification occurred at about $1048^{\circ}\text{C}.$, but before this happened there was considerable surfusion, while at the end of the solidification a large evolution of heat occurred. These curious changes are indicated on the curve at A and B respectively.

It appears probable that the metallic compound, SbAl , which was first described by Wright in 1892, decomposes after solidification, thus giving rise to this evolution of heat. The ease with which alloys containing AlSb break up into powder and rapidly oxidise substantiates this view.

Dr. Rosenhain's remarks, relating to double eutectic points in certain

FIG. 13.

aluminium alloys, rather reminded the speaker of some peculiar phenomena he obtained at the Royal Mint in 1897, while investigating the gold-aluminium alloys. He found a series of double changes in the region indicated by A and B in Fig. 14.

With the exception of the lines A and B, the equilibrium curve is the one obtained by Heycock and Neville. The second series of changes (line B) appear to be the result of some decomposition, as in the case of the AlSb alloys, and they are accompanied, in most instances, also by an evolution of heat. Unlike the AlSb alloys, however, the change does not occur immediately after the completion of the solidification, but at about $20^{\circ}\text{C}.$ below this point. The nature of the change is shown in Fig. 15.

A represents the first change and B the sudden evolution of heat.

The high surface tension of aluminium and its alloys in the molten state has militated considerably against its use for castings. In no way has this extraordinary property been better demonstrated than by the experiments of Margôt, who passed an electric current through aluminium wires until the metal was above its melting-point, and then twisted the wires, either by means of a small motor or a magnet, through an almost unlimited number of revolutions, without fracture.

Curiously enough, 5 per cent. of bismuth gives a malleable alloy with

196 FAILURE OF THE LIGHT ENGINEERING ALLOYS,

aluminium and greatly reduces its surface tension for casting purposes. This metal also can be machined with ease.

FIG. 14.

On the whole, one cannot help feeling that the results obtained, so far, with aluminium alloys have been somewhat disappointing.

Under certain conditions, aluminium and its alloys oxidise very rapidly. This is particularly the case with AlSb alloys; the one previously mentioned,

FIG. 15.

containing 18 per cent. aluminium and 82 per cent. antimony, will, if kept for some time, drop to powder, and in this condition it refuses to melt even at $1,100^{\circ}\text{C.}$; owing to the oxidation of the aluminium which has occurred.

Mercury, too, has a great influence on the oxidisibility of aluminium. If

an aluminium plate be rubbed with mercury, it will, in a few minutes, become too hot to hold in the hand and large flakes of alumina will drop off it.

Finely divided aluminium when mixed with an easily reducible oxide will, under certain conditions, "go off" with explosive violence, and this is particularly so when it is mixed with red lead. It is perfectly possible to fire such a charge of finely divided aluminium and red lead, mixed in chemical proportions, electrically, by means of a bridge wire, and even with two ounces of the mixture, suitably enclosed, a considerable effect can be obtained. He spoke feelingly in connection with this matter, as he once placed such a charge in a fireplace in a lecture-room, hoping thereby to minimise the amount of lead fume in the room. Unfortunately, the explosion was more violent than was anticipated, and it not only shattered a heavy fire screen placed in front of it, but it also effectually cleaned the chimney, which had apparently not been swept for some considerable time, much to the distress of the audience.

Dr. T. Martin Lowry pointed out that the majority of metals when alloyed with iron harden it, decrease its permeability and increase its retentiveness. It was curious that in the case of aluminium and silicon the reverse took place. Aluminium and antimony also had the property of developing magnetic properties in manganese—a metal which in the pure state was devoid of marked magnetic properties. He did not know whether these three elements (Al, Si, Sb), possessed the property of raising instead of lowering the transition-temperature of γ to β or α iron and was anxious to secure information on this point. He might, however, call attention to the fact that two of the three elements (Al, Sb) were amongst those that showed an expansion after solidification, since this suggested an alternative explanation, namely, that they might have the property of loosening the texture of alloys in which they were present and so increase the "softness" of a magnetic metal such as iron or a potentially-magnetic metal such as manganese.

Mr. E. F. Law (*in reply*) said that he wished to thank the various speakers for the very generous way in which they had referred to his Paper. It had been written very largely with the object of raising a discussion, and he was much gratified with the result. During the discussion of a paper interesting points were raised and valuable information elicited which would otherwise escape publication, and for that reason alone the discussion was often of greater value than the paper itself. He would like to take this opportunity of urging the desirability of publishing, in some form or other, those results of research which were either negative, inconclusive, or unexplained. The discussion on the present Paper, for example, had brought out the fact that as far back as 1897 the double break in the cooling curve of the aluminium-gold alloys had been noticed at the Royal Mint, and doubtless the phenomenon had also been observed by Heycock and Neville, but yet the equilibrium curve of these alloys was invariably given without this second break, presumably because no explanation was forthcoming of its existence. It would be interesting to know how many workers had since noticed the phenomenon and ignored it for a similar reason.

As regards Dr. Seligman's view that we should "suffer a distinct loss if the attention of metallurgists were devoted to this subject at the present moment," he (Mr. Law) could not agree. In order to fully understand the properties of the alloys already in common use, it was essential that the properties of the metals should be investigated, and it was inconceivable that any investigation which would throw light on the phenomena occurring

198 FAILURE OF THE LIGHT ENGINEERING ALLOYS

in single metals could in any way hinder the advance of our knowledge concerning their alloys.

In reply to Mr. Ristori, the effect of mechanical treatment in preventing spontaneous disintegration had been briefly referred to in the Paper. The particular alloys referred to were those of zinc and aluminium, but apart from these alloys there was a lack of information on the subject. It was a matter for congratulation that Mr. Merrett had been prevailed upon to speak. He was a perfect mine of information on things metallurgical, and when he could be induced to talk about his unpublished researches, his contributions were always of the greatest value and interest.

Dr. Rosenhain and Dr. Seligman both adopted the view that the failure of the aluminium alloys to meet expectations was rather the fault of the expectations than of the alloys. This is another way of stating the case, and it is a matter of choice which way we look at it.

Dr. Rosenhain had attempted to follow the disintegration of the aluminium alloys under the microscope, and evidently his efforts had been no more successful than his own. It was necessary to employ a high power, and it was extremely difficult to observe the process at the critical time.

Dr. Rosenhain has taken exception to a remark in the Paper which, he says, was made "apparently with the wish to suggest that the thermal arrest-points were in reality due to a transformation in the aluminium and not to the formation of a eutectic." He adds, "If Mr. Law had seen the full facts as they lay before himself and Mr. Lantsberry when that statement was made, this criticism would not have been made." Precisely: but some of the facts had been suppressed; and the criticism was surely amply justified inasmuch as Dr. Rosenhain had admitted the existence of the double break, of which no notice had been taken and to which no reference had been made. Whether this property of the alloys could be utilised technically or not was, of course, an open question; but there was certainly no sound scientific reason for ignoring it and treating it as though it did not exist.