## V. WORKING LIQUIDS FOR BUBBLE CHAMBERS.

### V.1. G.E. Kalmus - Survey of some bubble chamber liquids.

There are many liquids which could be used in large chambers, and if liquid-liquid and gas-liquid solutions are included this number becomes even greater. I will limit this survey to liquids and gas-liquid mixtures which seem to us to offer some special advantages.

Table I lists most of the relevant properties of a selection of liquids. The radiation length (conversion length) is calculated from the formula in Rossi "High Energy Particles", p. 220.

This list is by no means complete, since it neglects the fluoro-carbons used by Hahn at Fribourg (Rev. Sci. Inst. 29, 2, 184, (1958), which have radiation lengths of about 25 cm, and also the $SnCl_4$ - $CClF_3$ mixtures used by Argan et al. (Nuovo Cimento, X, 1, (1958). However this last micture does not appear to us to offer many advantages.

The operating conditions of propane, propane-methyl-iodide, methyl-iodide, tungsten hexafluoride, $CF_3Br$ and $CF_3I$ were found experimentally by us at University College, London, using a 1 1/2" diaphragm operated, Monel chamber with fused quartz wondows, The other results are from the relevant literature.

Of this list, I will not consider in detail tin tetrachloride due to its exceedingly high operating temperature and high corrosiveness, hydrogen bromide due to its high probable operating pressure, methyl-bromide due to its instability and the fact that it offers little advantage over $CF_3Br$ which operated at lower temperature and pressure, and $CF_2Br_2$ which offers little advantage over $CF_3Br$ but operates at a much higher temperature.

Tungsten hexafluoride. This substance was first used by Teem's group at California Institute of Technology (Nuovo Cimento 6, 1480, (1957)). Subsequently we successfully used it in our chamber and found that the operating temperature and pressure was substantially lower in our chamber than in his. However, we found that the windows (both fused quartz and pyrex) became etched after a period of several days, especially by the vapour phase. The monel appeared to be unattacked but the fluon gaskets were somewhat discoloured. The conclusion reached

T A B L E I

| MATERIAL | | OPERATING TEMP. °C | OPERATING PRESSURE ATM | OPERATING DENSITY $g/_{ml}$ | RADIATION LENGTH $g/_{cm^2}$ | RADIATION LENGTH cm | INTERACTION LENGTH cm |
|---|---|---|---|---|---|---|---|
| HYDROGEN | $H_2$ | - 246 | 4.7 | 0.06 | 68.7 | 1145 | 445 |
| PROPANE | $C_3H_8$ | 58 | 21 | 0.43 | 47.3 | 110 | 115 |
| TUNGSTEN HEXAFLUORIDE | $WF_6$ | 128 | 20 | 2.6 | 9.8 | 3.7 | 41 |
| TIN TETRACHLORIDE | $SnCl_4$ | 270 | 20 | 1.4 | 12.7 | 9.0 | 74 |
| XENON | Xe | - 19 | 26 | 2.3 | 8.6 | 3.7 | 56 |
| HYDROGEN BROMIDE | H Br | $\sim$ 50 | $\sim$ 42 | $\sim$1.5 | $\sim$ 12 | $\sim$ 8 | $\sim$ 75 |
| METHYL BROMIDE | $CH_3Br$ | $\sim$146 | $\sim$ 26 | $\sim$ 1.1 | $\sim$ 13 | $\sim$ 12 | $\sim$ 85 |
| METHYL IODIDE | $CH_3I$ | 210 | 31 | 1.7 | 9.4 | 5.5 | 67 |
| 50o/o METHYL IODIDE 50o/o PROPANE BY VOL. | | 110 | 30 | 1.1 | 11.0 | 10 | 88 |
| 25o/o METHYL IODIDE 75o/o PROPANE BY VOL. | | 95 | 27 | 0.78 | 13.6 | 17.4 | 100 |
| TRIFLUOROBROMO METHANE | $CF_3Br$ | 30 | 18 | 1.5 | 16.7 | 11.0 | 59 |
| DIFLUORODIBROMO METHANE | $CF_2Br_2$ | 146 | 19 | 1.6 | 13.7 | 8.6 | 62 |
| TRIFLUOROIODO METHANE | $CF_3I$ | 80 | 17 | 1.9 | 11.7 | 6.2 | 53 |

was that although chambers of a very few litres might be operated without too great difficulty, larger capacities than this would provide formidable construction, corrosion and safety problems. In fact Teem's group have abandoned their 12" $WF_6$ chamber.

One other point that might be worth mentioning is that $WF_6$ is not very readily available, at any rate in England.

Xenon. This is relatively easy to handle, but due to its high price even if sufficient quantities were available for large chambers the cost would be prohibitive. The precautions against leaks and consequent loss of xenon would probably be as severe as for a highly toxic liquid. Glaser has built a 12" xenon chamber which he is operating at Berkeley and also the Russians are reported to be building such a chamber.

Methyl-iodide propane mixtures. It had been realised for some time that methyl-iodide would, but for its instability, be a convenient heavy liquid for bubble chamber. Pless first overcame this objection by using methyl-iodide propane mixtures. The action of the propane was twofold. Firstly it lowered the operating temperature and secondly it inhibited the decomposition to a certain extent. The operating conditions reported second-hand to us, however, conflicted with our ideas concerning the gas-liquid system. Apart from this, however, the system offered a means of operating large chamber with heavy liquids under none too severe physical or chemical conditions. We thus investigated this system fully. The experimental results of it can be seen on Figure 8. The shape of the sensitive region appears to be general for all gas-liquid systems, the peak becoming less pronounced the closer the sensitivity vapour pressure curves of the two constituents.

We found that the coloration due to the decomposition became serious at concentrations of methyl-iodide greater than 50 o/o by volume. Even at 50 o/o $CH_3I$ when operating at the upper limit of sensitivity, i.e., at 120°C, the colour of the liquid was quite noticeable. It should be noted however that our chamber contained no material such as copper which would combine with the free iodine liberated, and thus clear the solution.

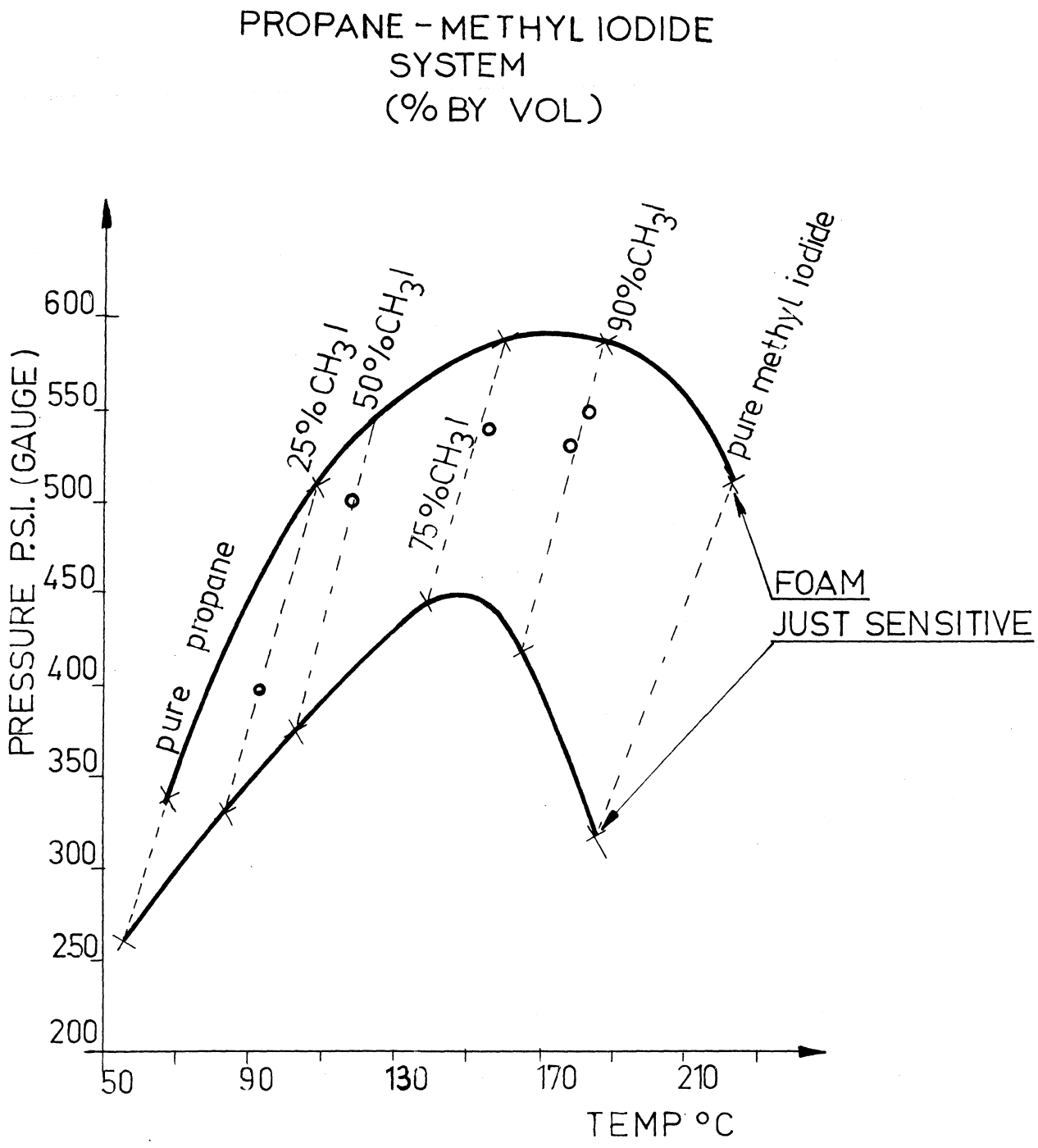
PROPANE - METHYL IODIDE
SYSTEM
(% BY VOL)
PRESSURE P.S.I. (GAUGE)
600
550
500
450
400
350
300
250
200
50
90
130
170
210
TEMP °C
Pure propane
25% $CH_3I$
50% $CH_3I$
75% $CH_3I$
90% $CH_3I$
pure methyl iodide
FOAM
JUST SENSITIVE

Fig.8

I understand that a 50 o/o $CH_3I$ - 50 o/o $C_3H_8$ by volume mixture was successfully used during a run at Saturne by the Ecole Polytechnique group. Also, I believe that their operating data is in good agreement with ours.

Trifluorobromo methane $CF_3Br$. This substance was first suggested by Kuznetsov (USPEKHI FIZ. NAUK, 64, 2, 361, (1958)),and by Bugg (Rev. Sci. Inst. 29, 587, (1958))its operating conditions being determined by the latter. Hahn also reports having used it. At University College, London, we determined its operating conditions, which agreed closely with Bugg's figures, and determined its sensitivity--vapour pressure curve and critical temperature and pressure. These can be seen on Figure 9.

$CF_3Br$ is non corrosive, stable, non-toxic, and non-inflammable. It operates at just above room temperature, and at a reasonably low pressure. It is relatively cheap, costing about £ 7 per litre in England. However, if large quantities were required this price might be substantially reduced.

Trifluoro iodo methane $CF_3I$. This was first suggested by Bugg as a possible bubble chamber liquid, and operated by us at University College, London. We found its operating conditions and vapour pressure curve up to its critical temperature. This is shown in Figure 10. It has a radiation length of 6.2 cm, and an interaction length of 53 cm. Unfortunately we found $CF_3I$ to be rather unstable, a flake like suspension appearing after a few minutes under operating conditions. We did not have sufficient of it available to carry out any tests as to the possibility of inhibiting the decomposition, although this would in our opinion be very worthwhile. We did however find it to be miscible with propane.

$CF_3I$ is not commercially available in England, its price in the U.S.A. being $ 30 per 100 gram.

General conclusions.

1. Xenon is not practical for large chambers due to its scarcity.
2. Tungsten hexafluoride presents formidable problems for any but small chambers.
3. It would be of interest to investigate the possibilities of using $CF_3I$ - propane mixtures, although at present the price of the former is prohibitive.

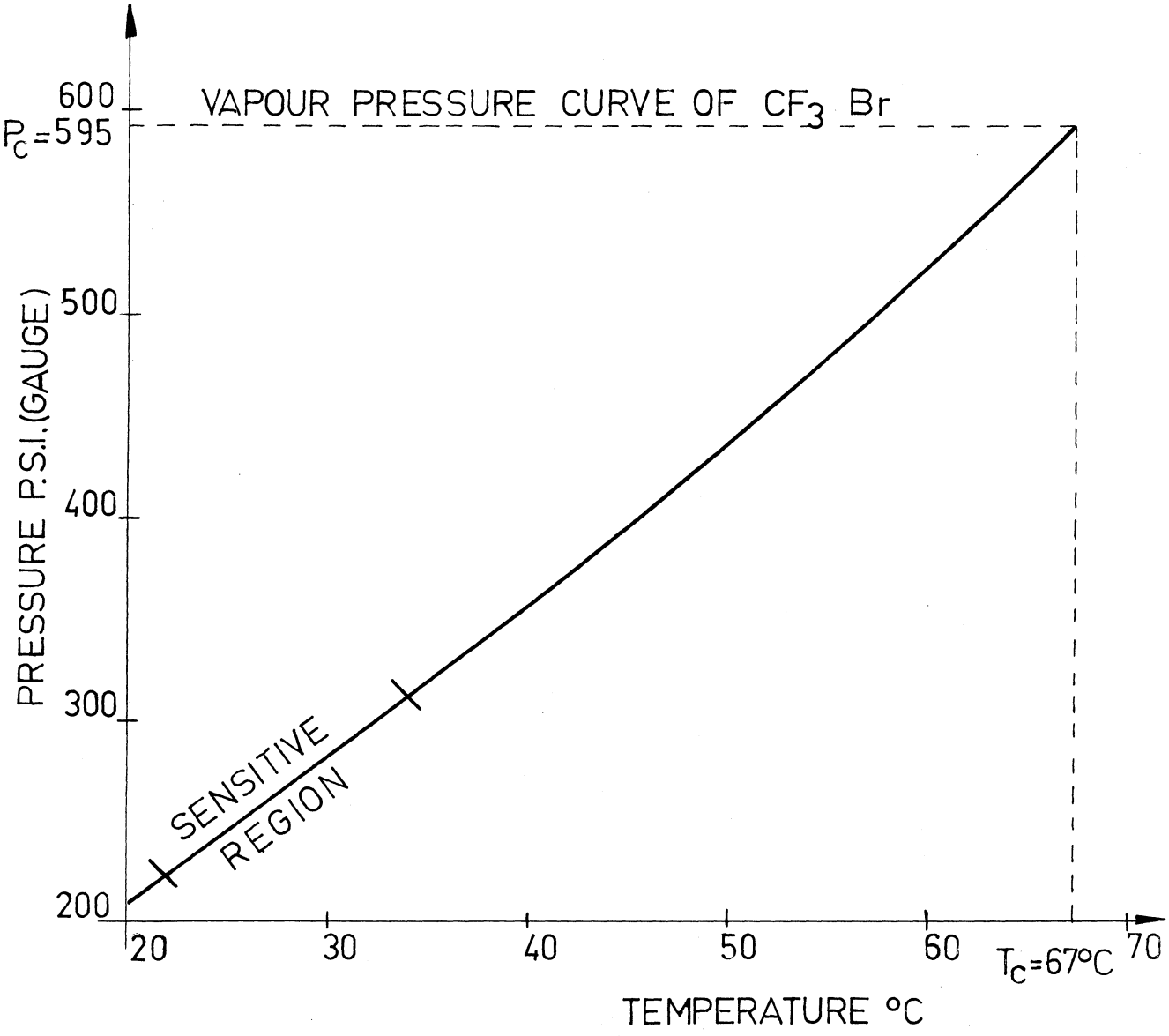
VAPOUR PRESSURE CURVE OF $CF_3$ Br
$P_c$=595
600
500
400
300
200
PRESSURE P.S.I.(GAUGE)
SENSITIVE REGION
20
30
40
50
60
$T_c$=67°C
70
TEMPERATURE °C

Fig. 9

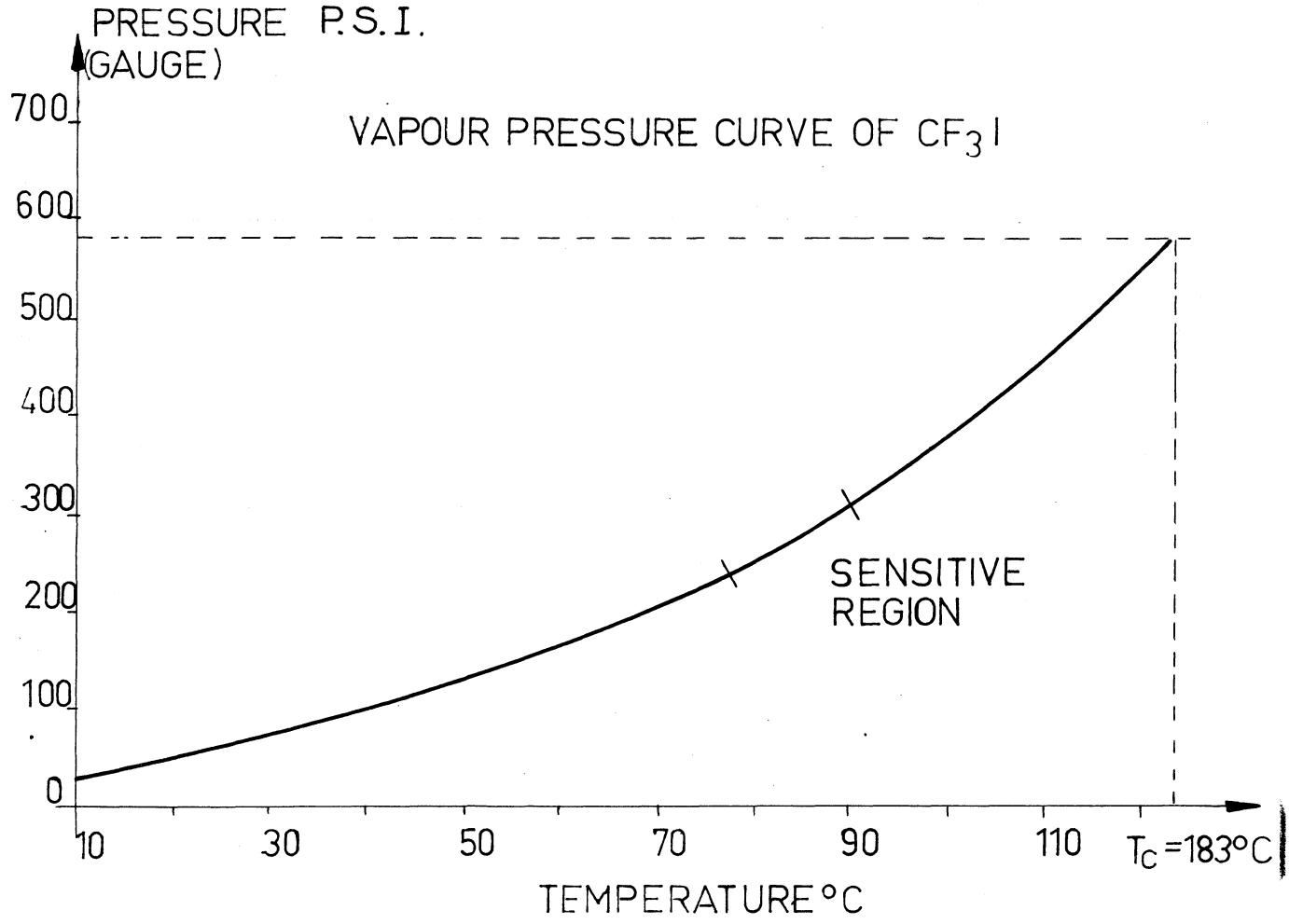
PRESSURE P.S.I.
(GAUGE)
VAPOUR PRESSURE CURVE OF $CF_3I$
700
600
500
400
300
200
100
0
SENSITIVE
REGION
10
30
50
70
90
110
$T_C$ =183°C
TEMPERATURE °C

Fig.10

4. Methyl iodide-propane mixtures can be used up to concentrations of 50 o/o $CH_3I$ by volume. Above this, decomposition is rapid, mainly due to the high operating temperature. It might well be possible to use mixtures of methyl iodide and either ethane, methane or ethylene, which might work to higher concentrations of $CH_3I$.
5. $CF_3Br$ was found to be easy to handle and operate. It can be used in any chamber designed for propane. This liquid appears to be ideal for experiments involving heavy liquids, where free target protons are not required. If free protons are required, mixtures of $CF_3Br$ and propane can almost certainly be used; their range of operating temperature being $30^\circ$ - $60^\circ$C.

   An exceedingly interesting mixture from this point of view would be $CF_3Br$ and $CH_3I$, the radiation length would be between 5.5 and 11 cm and the operating temperature of a 50 o/o - 50 o/o mixture would be about $90^\circ$C. However, since this mixture has not been tried, as far as I know, it is possible that decomposition may occur.
6. Some of the fluorocarbons used by Hahn might offer advantages in certain experiments where a medium radiation length is required.

Finally, it is our experience that unless there is a physical reason for using gas-liquid mixtures, pure liquids are far simpler to handle and operate.

DISCUSSION.

Hahn : What was the temperature of operation of the tungsten hexafluoride in your chamber ?

Kalmus : The chamber was fully sensitive at $128^\circ$C and the foam had definitely set in at about $147^\circ$C. Teem was still getting tracks at $147^\circ$C.

Salmeron : How do you define the sensitivity range ?

Kalmus : We did most of the experiments using a $Co^{60}$ source. We filled the chamber with a liquid, or a cetain concentration of a given liquid mixture, and we heated it up to a temperature at which we thought it would operate. We took then a series

of photographs with and without the radioactive source. If there was a significant increasing in number of bubbles when the source was present, we called that point the onset of sensitivity. The foam limit was easy to see. This method defines the limits to about 2°C.

Peyrou : When you define a foam limit, what does it mean in terms of expansion ratio ? Suppose you have foam at a given expansion ratio and given temperature, if you reduce the expansion ratio by a factor of, say, 2 will you still have foam or not ? Then if you have tracks you cannot say it is foam with the reduced expansion ratio .

Kalmus : We did not really do much on this. We always had a sufficient expansion ratio, in fact greater than it was necessary. There is another point we might bring out. It was our experience, with a small chamber, that it is easier to work with fewer liquids, even if it is necessary to work at few degrees higher. Less overpression is needed to recompress, it is easier to have homogeneity and consequently there is less optical distortions. I believe the Ecole Polytechnique group has some experience about this.

Bloch : Definitely up to few hundred expansions we can see index of refraction gradient inside the chamber, but with visual observation during expansion we do not see distortions in our tracks after few hundred expansions. We hope that the optical distortion diappears but we had not yet time to do accurate measurement on our tracks.

Hahn : Our experience is that when we use very fast recompression then we can prevent bubbles going to the top and optical distortions improve.

Bloch : Our experience is that we can allow in our chamber few bubbles going to the top. Perhaps this is due to the fact that our chamber is larger than your experimental chamber, but we shall have a more conclusive opinion after having done accurate measurements on our tracks.

Kalmus : We have noticed that when the mixture was uniform it was all right if bubbles never reached the top.

Henderson : How long does the Ecole Polytechnique group take to fill the present chamber (BP2) and to get it uniform ?

Bloch : To fill only, about half an hour. But if you consider the complete preparation of the chamber, starting from the beginning it takes 8 to 9 hours to have it ready for operation, including about 6 hours for heating.

Hahn : How do you measure the composition of the mixture ? Do you measure the density ?

Bloch : At present, with a ruler fixed at the chamber we just measure, to within 1 mm, the heights of the volumes occupied by the liquids. Accurate measurement of the composition will be made by spectroscopy by the "Institut du Pétrole".

Lagarrigue : We cannot measure the density because we would have to measure it during the expansion, when the liquid is in a metastable condition. We intend to check the density by looking for scattering of $\pi$-mesons on protons. If the scattering occurs in a plane parallel or perpendicular to the front glass it is possible to measure the density and the index of refraction.

5.2. B.Hahn - Survey of some bubble chamber liquids.

Among the liquids for bubble chambers there are two extremes in application:

1. Liquid hydrogen, which offers the possibility of doing experiments on free protons.
2. Liquids with high Z, which have high density and short radiation length.

I would like to give the operating conditions of several liquids with high Z that we have tried in our experimental chamber. The same liquids we might try now in our present chamber, which is larger.

Figure 11 summarises the operating conditions os such liquids. The operating pressure ($P_{operating}$) in atmospheres is plotted as a function of the operating temperature ($T_{operating}$) in degrees centigrades. The operating pressure goes up to about 30 atm (except for substances like water, for instance, for which it goes to 180 atm, but then it is not interesting). In Figure 11 the