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I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE CENTRATOM TRIESTE

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WORKSHOP ON SPACE PHYSICS:
"Materials in Micorgravity"
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A. PASSERONE
CNR
Istituto di Chimica Fisica Applicata dei Materiali
Genova, Italy

EVALUATION OF FLUXES IN THE MEASUREMENT OF THE SURFACE TENSION OF LIQUID METALS

by

P.COSTA Univ.Cagliari

A.PASSERONE, E.RICCI ICFAM-CNR Genova

- MEASUREMENTS OF THE SURFACE TENSIONS OF LIQUID METALS IN THE PRESENCE OF OXYGEN

2 TECHNIQUES → SESSILE DROP / LEVITATING DROP

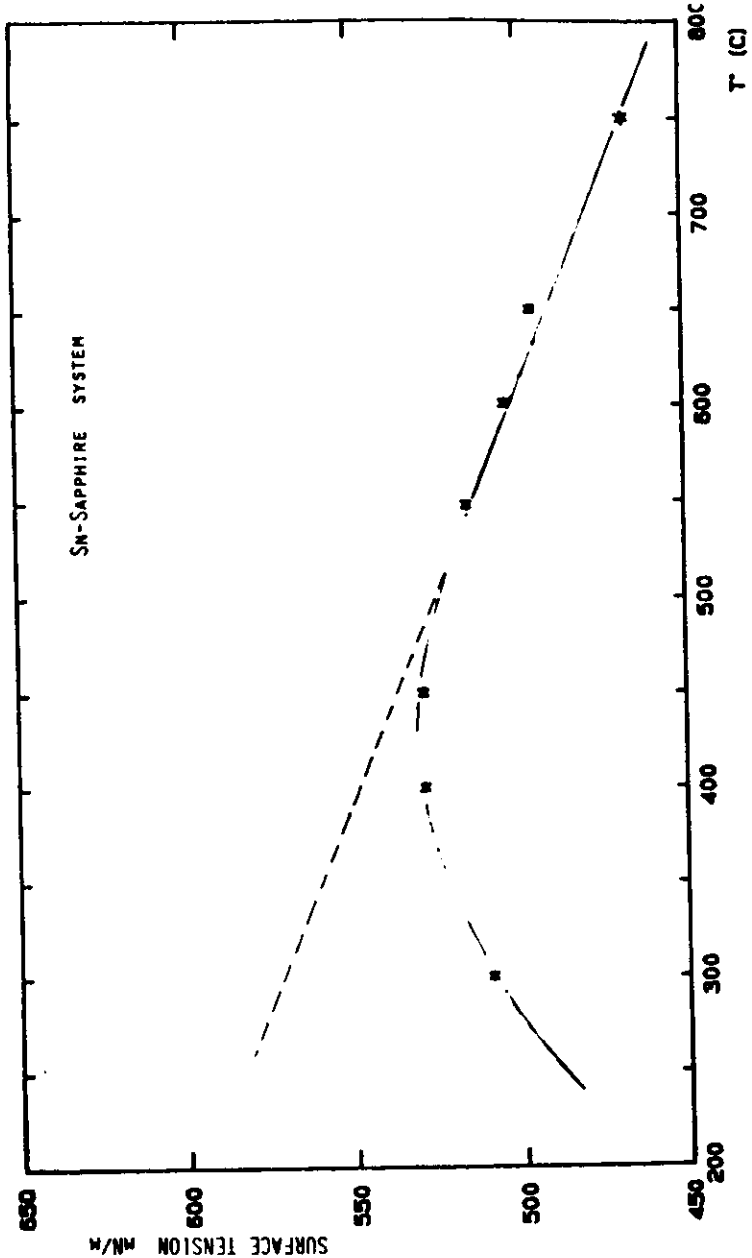
- COMMON FEATURES:
  1) ISOTHERMAL CONDITIONS
  2) VERY PURE METALS
  3) FLUX OF INERT GAS (He, Ar) + OXYGEN OR VACUUM

- AIM: TO MEASURE $\sigma = f(P_{O_2}, T)$

- TWO ASSUMPTIONS:
  1) THERMOD. EQUILIBRIUM BETWEEN FLOWI[NG] GAS AND METAL → Compute $X_{O\ BULK}$
  2) INITIAL "ZERO" OXYGEN CONTENT IN THE [...]

BUT CONDITIONS 1) & 2) are nearly never me[t]

IN FACT: LARGE SCATTER OF EXP. DATA. (See also → TI[...]

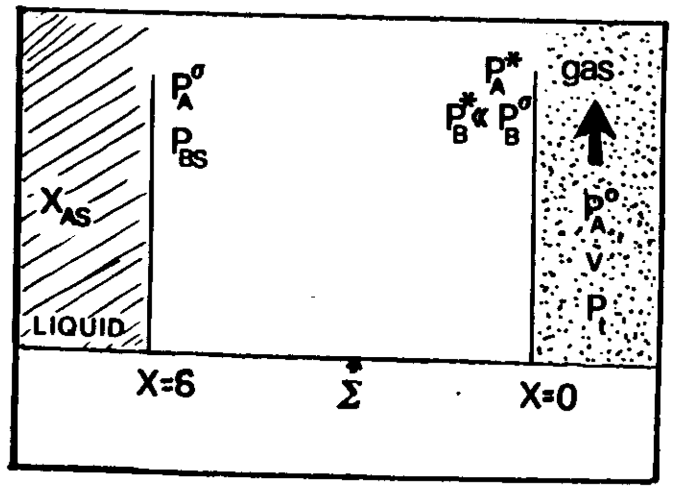


– THE MODEL.

- PURE LIQUID METAL (i.e. $P_A^\sigma = 0$)
- SMALL (Laminar), CONSTANT FLOW OF CARRIER GAS
- ONLY ONE OXIDE FORMS

$$(\alpha A)_g + (B)_g \rightarrow (BA_\alpha)_{sd}$$

- NEGLIGIBLE VAPOUR PRESSURE OF BA_α
- TOTAL PRESSURE P_t CORRESPONDING TO MEAN-FREE PATHS SMALLER THAN δ.



Theory.

- FROM REACT. (1)

$$P_A^{\alpha} \cdot P_B = P_{AS}^{\alpha} \cdot P_{BS} \qquad 2.$$

- CONSIDERING A LINEAR VARIATION OF P_A and P_B FOR $0 \leq x \leq \delta$ THE CONDITION :

$$P_A^* \gg P_{AS}$$

IS OBTAINED, IN ORDER TO HAVE REACT. 1.

IN THIS CASE, WE DEFINE:

$$\Phi = \delta \sqrt{\frac{\alpha k P_{BS}}{P_t D_A}} \qquad \text{THIELE MODULUS}$$

$$\varepsilon = \frac{\alpha P_{BS} D_B}{P_A^* D_A}$$

FOUR REGIONS ARE IDENTIFIED :

a) SLOW REACTIONS

$\Phi^2 \ll 1$

$\Phi^2 \ll \varepsilon$

- REACT. TIMES >> DIFF. TIMES
- FLUXES DEPEND ONLY ON D_A, D_B
- ≃ SAME RESULTS AS FOR NO-REACTIONS

b) FAST REACTIONS WITH EXCESS OXYGEN.

- DIFF. TIMES OF B > REACT. TIMES
- LARGE AVAILABILITY OF A
- REACT. 1 CONSUMES ALL B
- OXYGEN FLUX UNAFFECTED BY REACT. 1
- FLUX OF B HIGHLY ENHANCED

$\Phi^2 \gg \varepsilon$

$\Phi^2 \ll \frac{1}{\varepsilon}$

c) FAST REACTIONS WITH EXCESS METAL VAPOURS

- DIFF. TIMES OF A > REACT. TIMES
- LARGE AVAILABILITY OF B vapors
- REACT. 1 CONSUMES ALL A
- OXYGEN FLUX ENHANCED BY THE FACTOR $\phi \simeq \Phi$

$\Phi^2 \gg 1$

$\Phi^2 \ll \varepsilon^2$

d) INSTANTANEOUS REACTIONS

- REACT. TIMES $\ll$ (DIFF. TIMES)$_{A,B}$
- REACT. 1 CONFINED IN A "REACTION SURFACE" Σ at

$$X = \frac{\delta}{1+\varepsilon}$$

$\Phi^2 \gg 1/\varepsilon$

$\Phi^2 \gg \varepsilon^2$

- OXYGEN FLUX ENHANCED BY THE FACTOR $\phi \simeq 1 + \varepsilon$

…STIMATION OF FLUXES.

For each region, the flux of oxygen at the liquid-vapour interface can be calculated.

For regions a and b:

$$N_{AS} = \frac{f \cdot v \cdot P_A^{\circ}}{RT\left(1 + f\,P_e\right)} \qquad P_e = \frac{v \cdot \delta}{D_A}$$

For region c:

$$N_{AS} = \frac{f\,v\,P_A^{\circ}}{RT}\;\frac{\Phi}{\Phi + f\,P_e}\;\frac{1}{1 + \dfrac{D_B\,P_{BS}\,\alpha^2}{D_A\,P_{AS}\,\tau^{(\alpha+1)}}}$$

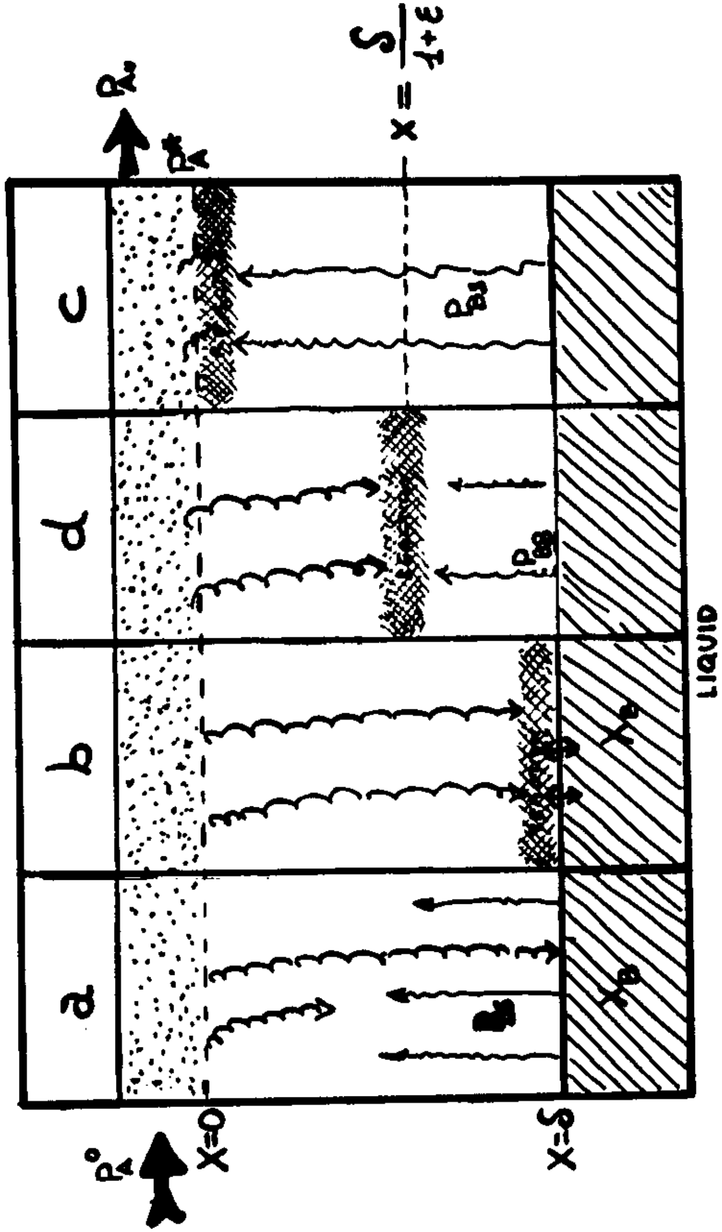
For region d:

$$N_{AS} = \frac{f\,v\,P_A^{\circ}}{RT} \cdot \frac{1 + \varepsilon_0}{1 + f\,P_e} \cdot \frac{1}{1 + \dfrac{D_B\,P_{BS}\,\alpha^2}{D_A\,P_{AS}\,\tau^{(\alpha+1)}}}$$

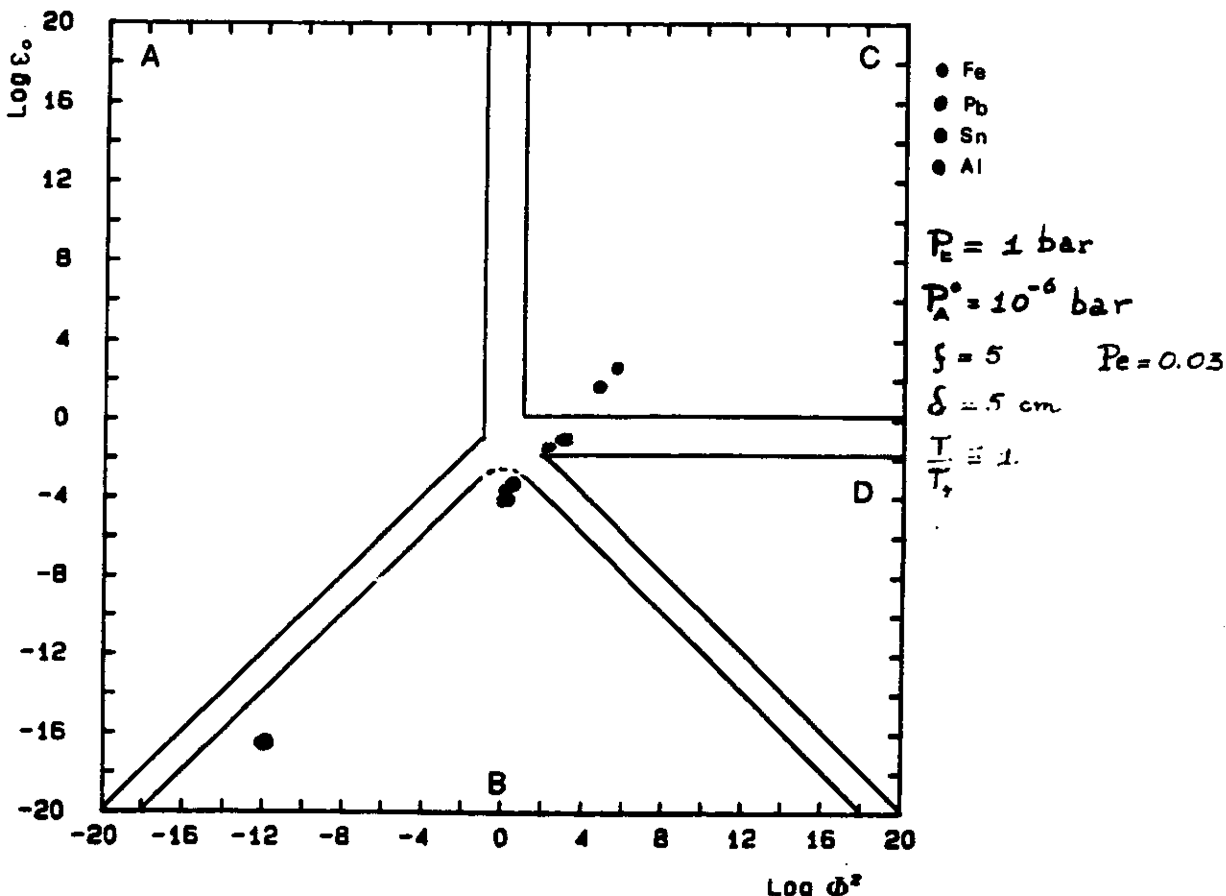
From N_{AS} the times necessary to saturate the bulk and the surface of the drops can be calculated:

$$\theta_b = \frac{x_{AS}\,\rho_B\,v_d}{2 M_B\,S_d\,N_{AS}}$$

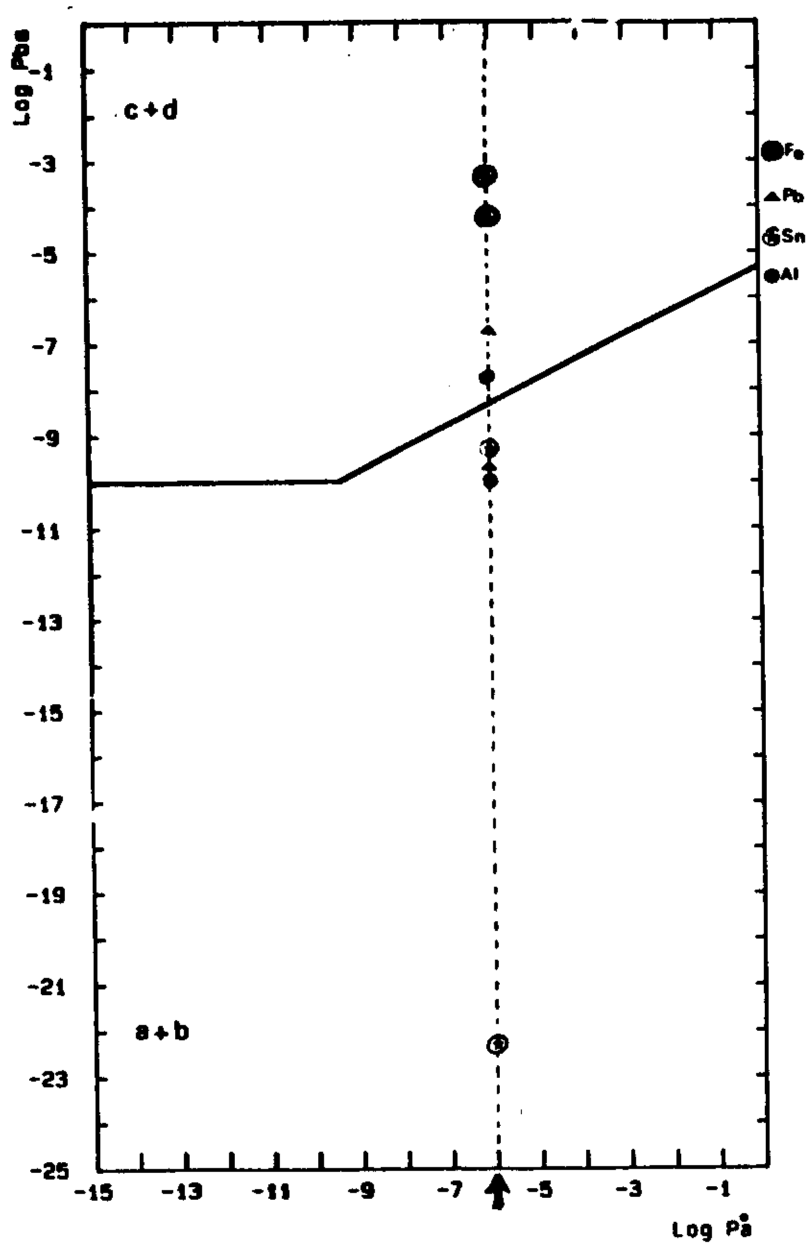
$$\theta_M = \frac{M}{N_{AS}} \qquad \text{where } M \cong 3 \cdot 10^{-9}\ \text{mole/cm}^2$$



METAL	OXIDE	T K	REACTION	N_{AS} MOLE CM²/SEC	θ_b SEC	θ_M SEC
AG	Ag_2O	1273	ABSENT	9.6 E-13	1.5 E9	3.2 E3
AL	Al_2O_3	973	B	1.2 E-12	1.1 E1	2.5 E3
			C	2.8 E-51	4.6 E39	1.1 E42
CU	CuO	1473	ABSENT	7.9 E-13	1.8 E9	3.8 E3
CO	CoO	1823	ABSENT	6.4 E-13	1.6 E8	4.7 E3
FE	FeO	1823	C	3.3 E-16	4.0 E11	8.9 E6
NI	NiO	1773	ABSENT	6.6 E-13	5.8 E8	4.6 E3
PB	PbO	650	B	1.8 E-12	1.4 E4	1.7 E3
			C	2.2 E-26	1.1 E18	1.3 E17
SN	SnO_2	550	B	2.1 E-12	2.8 E1	1.4 E3
"	"	1023	B	1.1 E-12	3.7 E6	2.6 E3
			C	9.9 E-21	4.3 E14	3.0 E11



$\log \varepsilon_0 = 1.07 \log \Phi^2 - 3.9$



Log Pas
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
-25
c+d
a+b
Fe
Pb
Sn
Al
-15
-13
-11
-9
-7
-5
-3
-1
Log Pa°