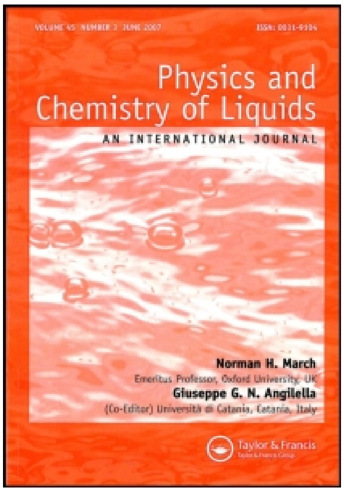

Physics and Chemistry of Liquids
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713646857

The absolute thermoelectric powers of liquid alloys in fifteen binary systems

R. Tougas[a]
[a] Head, Department of Metallurgical Engineering Ecole Polytechnique, (Université de Montréal), Montreal, P.Q., Canada

To cite this Article Tougas, R.(1970) 'The absolute thermoelectric powers of liquid alloys in fifteen binary systems', Physics and Chemistry of Liquids, 2: 1, 13 — 18
To link to this Article: DOI: 10.1080/00319107008084073
URL: http://dx.doi.org/10.1080/00319107008084073

Physics and Chemistry of Liquids. 1970. Vol. 2. pp. 13–18

Printed in Great Britain

The Absolute Thermoelectric Powers of Liquid Alloys in Fifteen Binary Systems

R. TOUGAS

Head, Department of Metallurgical Engineering
Ecole Polytechnique (Université de Montréal)
Montreal, P.Q.
Canada

Received November 5, 1969

Abstract—The absolute thermoelectric powers of liquid alloys as a function of temperature and composition are reported for fifteen Bi-, Cd-, In-, Pb- and Sn-base systems.

Introduction

Much theoretical work has been done in the past few years on the electronic properties of liquid metals (see, for instance, the reviews by Cusak[1] and by Wilson[2], and the Proceedings of the 1966 International Conference on the Properties of Liquid Metals[3]). A fair amount of data is available on certain properties such as the resistivity, but little experimental work has been carried out on the absolute thermoelectric power of liquid alloys.

The absolute thermoelectric power of liquid alloys as a function of temperature and composition are reported here for the following systems:

Bi–Cd	Cd–In	In–Pb	Pb–Sn	Sn–Tl
Bi–In	Cd–Pb	In–Sn	Pb–Tl	
Bi–Pb	Cd–Sn	In–Tl		
Bi–Sn	Cd–Tl			
Bi–Tl				

Experimental and Results

(a) *Measurement of the Seebeck emf* ($E_{A/\text{alloy}}$) *as a function of temperature of liquid couples of pure metal A and alloy* $A_{1-X}B_X$, *X being the atom fraction.*

The $E_{A/\text{alloy}}$ versus T (absolute temperature) function was determined using the experimental setup described in reference 4 and an automatic data acquisition system which could make digital measurements at $1\frac{1}{2}$-second intervals of the D.C. voltages corresponding to T_1 (the reference temperature), $E_{A/\text{alloy}}$, and T_2 (the varying temperature). T_1 being kept constant, when T_2 was around 250–275°C higher than T_1, the hot junction was allowed to cool down to the reference temperature, while readings were continuously taken by the data acquisition system which recorded the data on paper tape. The resolution of each reading was one microvolt. This tape was then fed to a digital computer programmed to linearly interpolate between successive T_1 and T_2 readings and calculate the ΔT corresponding to each $E_{A/\text{alloy}}$ reading. These values (400–500 pairs) were then used for the curve fitting calculations by the least square method.

It was found that the following equation

$$E_{A/\text{alloy}} = A_0 + A_1(\Delta T) + A_2(\Delta T)^2 \tag{1}$$

fitted the experimental data, most of the time within 1 microvolt. A_0, A_1 and A_2 are constants.

(b) *Determination of* $P_{A/\text{alloy}}$ *and* S_{alloy}

The thermoelectric power $P_{A/\text{alloy}}$ of thermocouple A/alloy was found from the relation

$$P_{A/\text{alloy}} = \frac{\mathrm{d}E_{A/\text{alloy}}}{\mathrm{d}(\Delta T)} = \frac{\mathrm{d}E_{A/\text{alloy}}}{\mathrm{d}T} = A_1 + 2A_2(\Delta T) \tag{2}$$

Following the sign convention given by Cusak[1], the absolute thermoelectric powers (S) of the pure metals and alloys were calculated from the following relation:

$$P_{A/\text{alloy}} = S_{\text{alloy}} - S_A \tag{3}$$

For the present calculation, the absolute thermoelectric power of lead given by Marwaha in Ref. 3, p. 618, was chosen as our primary reference value. According to this author, S_{Pb} between 600 and 1000 °K may be represented by this equation

$$S_{\text{Pb}} = -5.7 \times 10^{-3} T \tag{4}$$

S_{Pb} being in microvolts/ °K and T, in degrees Kelvin.

(c) *Metals used*

The metals used were of the following guaranteed purity (Cominco metals):

Metal	Purity	Typical impurities (in p.p.m.)
Bi	99.999	Cu: 1.0; Fe: 0.5; Pb: 0 5; Ag: 1.0
Cd	99.999	Bi: 0.3; Cu: 0.5; Fe: 1.0; Pb: 1.0
In	99.999	Cd: 1.0; Tl: 1.0; Cu: 1.0; Sn: 1.0; Pb: 2.0
Pb	99.999	Sb: 0.5; Bi: 2.0; Cu: 0.5; Fe: 0.3; Ag: 0.2; Tl: 1.0
Sn	99.999	Sb: <1.0; Bi: 0.3; Cu: 0.5; In: 0.5; Fe: 0.3; Pb: 2.0
Tl	99.9999	Al, Ca, Cu, Pb, Mg, Si: 0.1 each; Fe: 0.2; S: 0.5, Ag: <.1

The alloys were fabricated by synthesis.

(d) *Results*

The results for the fifteen systems which were studied are given in the table. The values of the absolute thermoelectric powers of the liquid alloys are given in microvolts/°K. For each composition S varies linearly with T in the range that was studied experimentally; this range is indicated next to the system identification. The results were generally reproducible within ± 0.04 microvolts/°K; on many occasions, they were reproduced within 0.02 microvolts/°K.

Conclusion

Since no general satisfactory model exists to properly explain the thermoelectric power of liquid metals and alloys, these experimental results are presented in the hope that they might raise some new interest on the subject and help theoreticians in verifying certain models.

Among the various observations that one may make from these experimental results, it is interesting to note, for example, that the thermoelectric powers P of the liquid thermocouples Sn/Sn-Bi are relatively quite small (these can be calculated using Eq. (3)). On the other hand, it is known that the tin-bismuth system is almost thermodynamically ideal, that is, the enthalpy of mixing of its alloys is relatively close to zero. This observation and others[4] seem to point in the direction of a relation between the thermoelectric and thermodynamic properties of liquid alloys, and hopefully a better understanding of the liquid state.

Table 1 The absolute thermoelectric powers of liquid alloys as a function of temperature for the following binary systems

(1) Pb–Cd	(6) Tl–In	(11) Tl–Bi
(2) Sn–Cd	(7) Cd–Bi	(12) In–Cd
(3) Tl–Cd	(8) In–Bi	(13) Sn–Pb
(4) Pb–In	(9) Pb–Bi	(14) Pb–Tl
(5) Sn–In	(10) Sn–Bi	(15) Tl–Sn

(1) $Pb_{1-X}Cd_X$ (625–875 °K)			(2) $Sn_{1-X}Cd_X$ (625–875 °K)			(3) $Tl_{1-X}Cd_X$ (625–875 °K)		
	S(microvolts/°K)			S(mocrovolts/°K)			S(microvolts/°K)	
X_{Cd}	630 °K	830 °K	X_{Cd}	630 °K	830 °K	X_{Cd}	630 °K	830 °K
0.00	−3.59	−4.73	0.00	−0.62	−0.84	0.00	−0.73	−1.18
0.10	−3.52	−4.39	0.10	−0.53	−0.80	0.10	−1.16	−1.83
0.20	−3.07	−3.83	0.20	−0.52	−0.79	0.20	−1.46	−2.22
0.30	−2.73	−3.27	0.30	−0.48	−0.78	0.30	−1.66	−2.46
0.40	−2.46	−2.72	0.40	−0.46	−0.78	0.40	−1.81	−2.67
0.50	−1.94	−2.41	0.50	−0.46	−0.78	0.50	−1.80	−2.68
0.60	−1.66	−2.09	0.60	−0.45	−0.78	0.60	−1.63	−2.50
0.70	−1.35	−1.67	0.70	−0.41	−0.73	0.70	−1.30	−2.13
0.80	−0.93	−1.27	0.80	−0.30	−0.63	0.80	−0.83	−1.49
0.90	−0.43	−0.56	0.90	−0.07	−0.30	0.90	−0.15	−0.58
1.00	+0.58	+0.79	1.00	+0.58	+0.79	1.00	+0.58	+0.79

(4) $Pb_{1-X}In_X$ (625–875 °K)			(5) $Sn_{1-X}In_X$ (625–875 °K)			(6) $Tl_{1-X}In_X$ (625–875 °K)		
	S(microvolts/°K)			S(microvolts/°K)			S(microvolts/°K)	
X_{In}	630 °K	830 °K	X_{In}	630 °K	830 °K	X_{In}	630 °K	830 °K
0.00	−3.59	−4.73	0.00	−0.62	−0.84	0.00	−0.73	−1.18
0.10	−3.40	−4.30	0.10	−0.63	−0.87	0.10	−0.97	−1.55
0.20	−3.02	−3.78	0.20	−0.65	−0.92	0.20	−1.10	−1.84
0.30	−2.74	−3.38	0.30	−0.70	−1.00	0.30	−1.53	−2.19
0.40	−2.43	−2.96	0.40	−0.78	−1.10	0.40	−1.66	−2.32
0.50	−2.09	−2.63	0.50	−0.83	−1.20	0.50	−1.82	−2.49
0.60	−1.88	−2.37	0.60	−0.97	−1.36	0.60	−1.82	−2.46
0.70	−1.78	−2.24	0.70	−1.05	−1.47	0.70	−1.82	−2.45
0.80	−1.63	−2.10	0.80	−1.17	−1.65	0.80	−1.71	−2.34
0.90	−1.52	−2.02	0.90	−1.23	−1.78	0.90	−1.60	−2.18
1.00	−1.40	−1.97	1.00	−1.40	−1.97	1.00	−1.40	−1.97

(7) $Cd_{1-X}Bi_X$ (625–875 °K)			(8) $In_{1-X}Bi_X$ (625–875 °K)			(9) $Pb_{1-X}Bi_X$ (625–875 °K)		
	S(microvolts/°K)			S(microvolts/°K)			S(microvolts/°K)	
X_{Bi}	630 °K	830 °K	X_{Bi}	630 °K	830 °K	X_{Bi}	630 °K	830 °K
0.00	+0.58	+0.79	0.00	−1.40	−1.97	0.00	−3.59	−4.73
0.10	−0.82	−1.22	0.10	−1.57	−2.16	0.10	−3.00	−4.00
0.20	−1.12	−1.65	0.20	−1.61	−2.14	0.20	−2.62	−3.48
0.30	−1.08	−1.53	0.30	−1.40	−1.95	0.30	−2.32	−3.08
0.40	−0.81	−1.23	0.40	−1.14	−1.67	0.40	−2.00	−2.66
0.50	−0.75	−1.03	0.50	−0.96	−1.37	0.50	−1.73	−2.42
0.60	−0.67	−0.95	0.60	−0.82	−1.21	0.60	−1.47	−2.04
0.70	−0.66	−0.95	0.70	−0.79	−1.15	0.70	−1.24	−1.76
0.80	−0.70	−1.00.	0.80	−0.79	−1.12	0.80	−1.12	−1.54
0.90	−0.71	−1.08	0.90	−0.79	−1.14	0.90	−0.93	−1.36
1.00	−0.73	−1.10	1.00	−0.73	−1.10	1.00	−0.73	−1.10

(10) $Sn_{1-X}Bi_X$ (625–875 °K)			(11) $Tl_{1-X}Bi_X$ (625–875 °K)			(12) $In_{1-X}Cd_X$ (625–875 °K)		
	S(microvolts/°K)			S(microvolts/°K)			S(microvolts/°K)	
X_{Bi}	630 °K	830 °K	X_{Bi}	630 °K	830 °K	X_{Bi}	630 °K	830 °K
0.00	−0.62	−0.84	0.00	−0.73	−1.18	0.00	−1.40	−1.97
0.10	−0.64	−0.90	0.10	−1.55	−2.10	0.10	−1.33	−1.86
0.20	−0.66	−0.97	0.20	−2.00	−2.71	0.20	−1.22	−1.78
0.30	−0.68	−1.00	0.30	−2.09	−2.82	0.30	−1.08	−1.62
0.40	−0.70	−1.02	0.40	−1.83	−2.50	0.40	−0.86	−1.42
0.50	−0.71	−1.03	0.50	−1.52	−2.09	0.50	−0.75	−1.25
0.60	−0.71	−1.05	0.60	−1.28	−1.77	0.60	−0.56	−1.03
0.70	−0.72	−1.07	0.70	−1.09	−1.52	0.70	−0.28	−0.73
0.80	−0.73	−1.10	0.80	−0.96	−1.34	0.80	−0.02	−0.40
0.90	−0.73	−1.10	0.90	−0.83	−1.19	0.90	+0.27	+0.06
1.00	−0.73	−1.10	1.00	−0.73	−1.10	1.00	+0.58	+0.79

(13) $Sn_{1-X}Pb_X$ (625–875 °K)			(14) $Pb_{1-X}Tl_X$ (675–900 °K)			(15) $Tl_{1-X}Sn_X$ (625–875 °K)		
	S(microvolts/°K)			S(microvolts/°K)			S(microvolts/°K)	
X_{Pb}	630 °K	830 °K	X_{Tl}	680 °K	880 °K	X_{Sn}	630 °K	830 °K
0.00	−0.62	−0.84	0.00	−3.88	−5.02	0.00	−0.73	−1.18
0.10	−0.87	−1.14	0.10	−3.84	−4.81	0.10	−1.13	−1.65
0.20	−1.10	−1.36	0.20	−3.65	−4.46	0.20	−1.51	−2.00
0.30	−1.19	−1.53	0.30	−3.30	−3.90	0.30	−1.64	−2.20
0.40	−1.57	−1.92	0.40	−2.82	−3.14	0.40	−1.71	−2.19
0.50	−1.71	−2.14	0.50	−2.07	−2.42	0.50	−1.65	−2.09
0.60	−2.14	−2.61	0.60	−1.49	−1.84	0.60	−1.52	−1.85
0.70	−2.33	−2.95	0.70	−1.06	−1.49	0.70	−1.31	−1.60
0.80	−2.78	−3.51	0.80	−0.95	−1.38	0.80	−1.10	−1.33
0.90	−3.12	−4.02	0.90	−0.86	−1.34	0.90	−0.77	−1.04
1.00	−3.59	−4.73	1.00	−0.84	−1.36	1.00	−0.62	−0.84

Acknowledgement

The author wishes to express his appreciation to the National Research Council of Canada for its financial support.

REFERENCES

1. Cusak, N. E., *Rep. Prog. Phys.* **26**, 361 (1963).
2. Wilson, J. R., *Met. Rev.* **10**, 381 (1965).
3. Adams, P. D., Davies, H. A. and Epstein, S. G., "The Properities of Liquid Metals", Taylor and Francis, London, 1967.
4. Tougas, R., *Can. Met. Quart.* **5**, 47 (1966).