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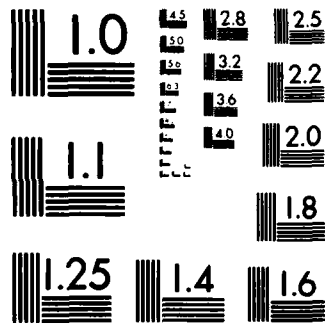
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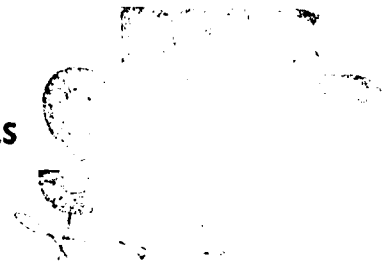
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# Ignition Delay Times of Propene Oxygen Argon Mixtures

by

Alexander Burcat and Josef Levitas

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IGNITION DELAY TIMES OF PROPENE OXYGEN  
ARGON MIXTURES

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Haifa, Israel

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ABSTRACT

The ignition delay times of Propene Oxygen Argon mixtures were measured in a shock tube. The concentrations ranged from 0.6% to 1.6%  $C_3H_6$  and 2.7% to 14.4% oxygen. The initial pressures were 50 to 133 torr, and the temperatures achieved were 1274 -1848 K.

The overall ignition delay equation for Propene Oxygen Argon mixtures has a value of

$$\tau = 5.3 \times 10^{-14} \exp[(37.5 \times 10^3)/RT] [C_3H_6]^{0.23} [O_2]^{-1.12} [Ar]^0 \text{ sec}$$

A kinetic scheme for the oxidation of propene is proposed. €

## INTRODUCTION

Propene is an important raw material in the production of polypropylene plastics. It was also found to be an intermediate in the decomposition of propane [1], the first step to occur by spontaneous thermal dehydrogenation. The decomposition was also found to occur in considerable quantities before any oxidation starts in the ignition process of propane [2].

When measuring the ignition delay time of propane [2,3], it is completely unclear whether the correlation found is that of propane or that of propane + propene + propyne, the latter being a degradation product of propene itself [4].

Thus the ignition delay values of propene are very important in elucidating this question.

## EXPERIMENTAL

The ignition experiments of propene were performed in a stainless steel shock tube whose diagram is given in Fig. 1. The tube is 50 mm in diameter (two inches) and 4 meters long. The driven section is 2.5 meters long. Mylar diaphragms of different gauges are used. They are burst by the driver's gas pressure. The driver gas used in this study was Airco pure grade helium. Two specially built valves divide the driven section. One of the valves is located in the middle of the tube thus permitting half of the tube to be filled with the reacting mixture while the other half is filled with a matched-impedance neutral mixture or argon.

The second valve allows separation of the end block of the shock tube from the main instrument in order to extract gas samples from the tube for analysis. The shock speed is measured near the end block over a distance of 200 mm by two piezoelectric gauges connected to a HP 3400 counter with a

resolution of  $\pm 0.1 \mu\text{sec}$ . The pressure is measured by a Kistler 603A piezoelectric gauge mounted into the end plate. A home made thin platinum heat transfer gauge is also mounted near the end plate of the shock tube.

The gases used were Matheson Propylene C.P. 99.0% pure, I.B. Miller Oxygen 99.5% pure and 99.9% pure argon.

Gas mixtures were prepared manometrically in stainless steel cylinders using a high pressure manifold. They were left overnight to mix before use. All mixtures used are listed in Table I.

The reflected shock temperatures were calculated using the standard conservation equations and the ideal gas equation of state, assuming frozen chemistry. The enthalpies of propylene were recalculated at the proper temperature range using statistical methods [5] and well determined spectroscopic data [6]. They were published elsewhere [7]. Oxygen and argon thermodynamic properties were taken from thermodynamic tables [8,9].

#### RESULTS AND DISCUSSION

As shown in Table I 6 propylene - oxygen - argon mixtures were used for the seven series of experiments for a total of 118 shocks. The mixtures were prepared in such a way as to permit direct deliniation of the power dependencies of the reactants in the assumed ignition delay equation

$$\tau = 10^{-x} \exp(+E/RT) [\text{C}_3\text{H}_6]^a [\text{O}_2]^b [\text{Ar}]^c \text{ sec}$$

In each of the performed shocks, the exact mixture and initial pressure were known. The recorded post shock experimental properties were the reflected temperature  $T_5$ , the density ratio  $\rho_1/\rho_5$  and the ignition delay time  $\tau$ . The experiments were spread over the temperature range in such a way as to permit maximum sensitivity to the determination of the so called "activation energy".

Figure 2 represents series A, B and C in a  $\log \tau$  vs  $1/T_5$  graph. Mixtures B and C have a threefold difference in the argon concentration (normalized for density ratio differences). The experiments show a large scatter and a mixture of the data of the two series, suggesting negligible or very small argon power dependency.

Figure 3 represents the  $\log \tau$  vs  $1/T_5$  for series D and E. The distance among the two lines is very small, approximately 0.08  $\log \tau$  units. Therefore, the propene power dependency should be:

$$\log \tau_E = a \log (0.8\% C_3H_6) + b \log (7.2\% O_2) + c \log A$$

$$\log \tau_D = a \log (4 \times 0.8\% C_3H_6) + b \log (7.2\% O_2) + c \log A$$

subtracting  $\tau_E$  from  $\tau_D$  and disregarding the small differences in argon concentration

$$\log (\tau_E - \tau_D) = a \log 4$$

$$a = \frac{\log (\tau_E - \tau_D)}{\log 4} = \frac{0.08}{0.6} = 0.138$$

Figure 4 represents groups F and G on a  $\log \tau$  vs  $1/T_5$  graph. As explained above the oxygen dependency can also be evaluated from the graph and it is found that  $b = -1.33$ .

Figure 5 represents the overall plot of  $\log \beta$  vs  $1/T$  for a maximum acceptable spread of  $2\sigma$ . The correlation was found with a statistical "student-t" program

$$\tau = 5.3 \times 10^{-14} \exp(+ (37150 \pm 1860) / RT) [C_3H_6]^{0.15 \pm 0.08} [O_2]^{-1.12 \pm 0.09} [Ar]^{0.20 \pm 0.198} \text{sec}$$

This correlation is found with 103 shocks. Using a  $3\sigma$  correlation with 115 shocks the data found are

$$\tau = 1.9 \times 10^{-14} \exp(+ (37680 \pm 2326) / RT) [C_3H_6]^{0.23 \pm 0.1} [O_2]^{-1.11 \pm 0.12} [Ar]^{0.0} \text{sec}$$

Table II contains a list of all shocks performed in this study and their pre and post shock parameters.

This investigation should be regarded in the proper perspective and compared with earlier studies on propane and propyne ignition. Burcat et al. [2] have reported the following equation for propane

$$\tau = 4.4 \times 10^{-14} \exp[(42.2 \times 10^3)/RT] [C_3H_8]^{0.57} [O_2]^{-1.22} [Ar]^0 \text{ sec}$$

The findings of this work on propene gives the following value

$$\tau = 5.3 \times 10^{-14} \exp[(37.5 \times 10^3)/RT] [C_3H_6]^{0.23} [O_2]^{-1.12} [Ar]^0 \text{ sec}$$

Unpublished results of propyne ignition [10] read approximately

$$\tau = 4 \times 10^{-12} \exp[(27.8 \times 10^3)/RT] [C_3H_4]^{-0.04} [O_2]^{-0.92} [Ar]^0 \text{ sec}$$

Therefore, the reasoning should be as follows: Earlier studies [1,2] have shown that propene is easily formed during the propane decomposition and that extensive decomposition occurs before oxidation steps start to influence.

The big similarity in ignition delay values of propane and propene suggest that the values measured for propane are really those of a mixture that contains mainly propylene and the propene influence is very great. However, propyne's influence on propane and propene is smaller.

The kinetic scheme of propene ignition should be calculated using earlier propane oxidation schemes [3] and eliminating from them the propane reactions such as the first 13 steps as proposed by Jachimowski [3]. In their place some of the elementary steps proposed recently by Kiefer [11] should be included.

The proposed scheme should include a list of reactions from different sources [3, 10-14]. Table III lists all the proposed scheme and the rate constants found in the literature.

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Table I. Experimental conditions of propylene mixtures.

Series	Concentrations %			$P_1$ ~ torr	Number of experiments	Parameters detected
	$C_3H_6$	$O_2$	Ar			
A	1.6	7.2	91.2	100	16	-
B	1.6	7.2	91.2	50	13	c
C	0.6	7.2	96.7	133	17	c
D	3.2	7.2	89.6	100	17	a
E	0.8	7.2	92.0	100	20	a
F	1.6	14.4	84.0	100	21	b
G	1.6	3.6	94.8	100	14	b

TABLE II

INCIDENT AND REFLECTED SHOCK PARAMETERS FOR A MIXTURE OF 3 SUBSTANCES.

THE MOLE FRACTION OF C3H6 IS 0.01600

A

THE MOLE FRACTION OF O2 IS 0.07200

THE MOLE FRACTION OF AR IS 0.91200

NO	P1	DRIFT	TREF	UREF	TAU	PE(ATM)
1	105.	6.78	1420.8	0.4172	517.0	4.4333
2	96.	6.71	1402.0	0.4153	629.0	3.9631
3	87.	6.62	1375.1	0.4125	842.0	3.4749
4	80.	7.36	1592.2	0.4340	122.0	4.3656
5	99.	7.61	1704.2	0.4450	70.0	5.6333
6	97.	6.86	1446.2	0.4199	305.0	4.2192
7	100.	7.50	1663.3	0.4410	61.0	5.4730
8	90.	7.04	1505.8	0.4261	213.0	4.5504
9	91.	7.58	1690.8	0.4446	61.0	5.1133
10	87.	7.67	1728.5	0.4479	61.0	5.0452
11	96.	7.28	1566.2	0.4343	77.0	4.9062
12	97.	7.16	1545.2	0.4301	123.0	4.7092
13	97.	7.12	1530.3	0.4286	113.0	4.6351
14	112.	7.34	1606.8	0.4363	113.0	5.7959
15	97.	7.00	1491.7	0.4246	307.2	4.4425
16	102.	6.59	1366.0	0.4110	650.0	4.0255

THE MOLE FRACTION OF C3H6 IS 0.01600

B

THE MOLE FRACTION OF O2 IS 0.07200

THE MOLE FRACTION OF AR IS 0.91200

NO	P1	DRIFT	TREF	UREF	TAU	PE(ATM)
17	51.	7.54	1670.0	0.4435	66.6	2.8334
20	57.	7.30	1572.2	0.4340	206.0	2.9065
21	49.	7.30	1593.4	0.4350	215.0	2.5015
23	50.	6.86	1452.4	0.4205	922.0	2.1905
24	54.	6.63	1376.9	0.4127	1331.0	2.1620
25	49.	7.53	1672.0	0.4429	122.9	2.7654
26	49.	7.06	1512.0	0.4273	512.0	2.3103
27	51.	7.00	1491.7	0.4246	532.5	2.3556
28	51.	7.18	1540.8	0.4306	389.0	2.4680
29	51.	7.05	1500.1	0.4264	606.3	2.3614
30	54.	7.33	1603.1	0.4350	308.0	2.7641

THE MOLE FRACTION OF C3H6 IS 0.00600

THE MOLE FRACTION OF O2 IS 0.02700

THE MOLE FRACTION OF AR IS 0.96700

NO	P1	DRIFT	TREF	UREF	TAU	PE(ATM)
101	140.	6.37	1626.5	0.4612	235.5	6.3631
102	173.	6.65	1761.7	0.4759	61.4	6.8350
103	133.	6.59	1728.3	0.4722	102.4	6.6389
104	131.	6.52	1695.0	0.4689	71.7	6.3519
105	134.	6.22	1550.2	0.4537	563.0	5.7003
106	136.	6.12	1518.3	0.4492	586.7	5.5466
107	130.	6.36	1593.5	0.4576	286.7	6.0744
108	138.	6.32	1601.9	0.4585	184.3	6.1251
109	135.	6.17	1537.4	0.4513	481.3	5.6162
110	135.	6.18	1543.1	0.4510	583.7	5.6403
113	130.	6.7	1630.1	0.4650	91.0	7.10785
115	130.	6.58	1725.6	0.4719	61.4	6.4734
117	129.	6.17	1550.7	0.4516	486.4	5.3702
116	133.	6.53	1600.0	0.4692	21.9	6.4724
119	138.	6.28	1583.0	0.4565	460.6	6.0173
120	138.	6.33	1608.0	0.4592	432.1	6.1614
121	135.	6.47	1670.0	0.4660	163.6	6.3980

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THE MOLE FRACTION OF C<sub>3</sub>H<sub>6</sub> IS 0.03200

THE MOLE FRACTION OF O<sub>2</sub> IS 0.07200

THE MOLE FRACTION OF AR IS 0.89600

NO	P1	DP101	TREF	URLE	TALL	PF(ATM)
302	09.	7.85	1443.7	0.3096	737.3	4.9237
303	07.	8.26	1547.1	0.4093	215.0	5.1347
304	09.	8.06	1495.6	0.4045	337.9	5.2341
305	09.	8.21	1533.4	0.4060	235.5	5.1632
305	100.	8.16	1522.1	0.4060	245.8	5.1400
307	09.	9.15	1510.9	0.4067	311.3	5.3611
308	100.	7.79	1423.4	0.3081	645.1	4.8622
309	100.	8.12	1511.0	0.4059	276.5	5.3607
310	09.	8.16	1521.0	0.4060	297.0	5.3676
311	100.	8.77	1687.0	0.4220	81.9	6.4821
312	103.	8.05	1492.3	0.4020	480.3	5.4251
313	100.	8.89	1722.8	0.4250	41.0	6.7145
314	102.	8.85	1712.0	0.4241	61.4	6.7760
315	101.	9.01	1750.0	0.4282	30.7	7.0185
316	09.	8.14	1515.4	0.4063	465.9	5.3539
317	103.	8.44	1596.7	0.4138	143.4	6.0688
318	09.	8.72	1618.8	0.4158	143.4	5.9695

THE MOLE FRACTION OF C<sub>3</sub>H<sub>6</sub> IS 0.00600

THE MOLE FRACTION OF O<sub>2</sub> IS 0.07200

THE MOLE FRACTION OF AR IS 0.92000

NO	P1	DP101	TREF	URLE	TALL	PF(ATM)
401	100.	6.40	1453.3	0.4222	604.0	4.0805
405	103.	7.01	1688.3	0.4573	72.0	5.3432
406	100.	6.23	1655.6	0.4530	123.0	5.0310
408	100.	6.80	1603.1	0.4484	123.0	4.7603
409	100.	7.04	1703.0	0.4568	72.0	5.2584
410	101.	6.25	1664.7	0.4549	113.0	5.1250
413	097.	7.20	1772.8	0.4659	31.0	5.4274
414	102.	6.84	1620.3	0.4502	102.0	4.9506
415	100.	6.31	1646.8	0.4530	65.5	4.9680
416	099.	6.57	1515.7	0.4391	235.0	4.3257
417	099.	6.25	1400.9	0.4265	432.0	3.8023
418	102.	6.72	1571.2	0.4451	164.0	4.7254
419	100.	6.41	1454.5	0.4327	409.6	4.0948
420	100.	6.40	1454.4	0.4324	379.0	4.0652
422	101.	6.34	1432.8	0.4301	522.0	4.0259
423	100.	6.22	1342.2	0.4256	901.6	3.8009
425	099.	6.33	1422.8	0.4297	573.0	3.9326
426	100.	6.73	1574.3	0.4458	174.1	4.6439
427	101.	6.44	1465.9	0.4337	471.0	4.1797

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THE MOLE FRACTION OF C3H6TS 0.01600

THE MOLE FRACTION OF O2 TS 0.14400

THE MOLE FRACTION OF AR TS 0.84000

NO	PI	DRIFT	TREE	URLE	TALL	PS(ATM)
201	05.	7.43	1453.7	0.4120	117.0	4.5019
202	09.	7.51	1474.9	0.4150	136.5	4.8080
203	102.	7.68	1525.5	0.4200	117.0	5.2437
204	100.	7.45	1458.2	0.4130	273.0	4.7681
205	09.	7.40	1444.2	0.4120	253.5	4.6402
206	02.	7.35	1422.0	0.4105	370.5	4.2303
207	04.	7.62	1507.6	0.4183	136.5	4.8001
208	08.	7.35	1420.0	0.4105	321.5	4.5158
209	04.	7.10	1380.5	0.4055	409.0	4.2945
210	100.	7.10	1440.5	0.4120	204.0	4.7159
211	101.	7.46	1466.3	0.4142	189.4	4.8576
212	106.	7.01	1361.1	0.4015	614.4	4.3732
213	103.	7.85	1569.7	0.4240	76.8	5.5522
214	101.	7.64	1512.1	0.4187	128.0	5.1153
215	102.	8.00	1647.6	0.4312	30.9	5.9552
216	07.	8.05	1631.0	0.4300	71.7	5.9101
217	102.	7.73	1530.2	0.4213	02.2	5.3225
218	100.	7.38	1430.1	0.4114	225.3	4.6587
219	00.	7.00	1611.0	0.4263	61.4	5.4016
220	105.	6.74	1272.0	0.3245	801.0	3.8765
221	100.	6.98	1331.1	0.4000	504.0	4.0722

THE MOLE FRACTION OF C3H6TS 0.01600

THE MOLE FRACTION OF O2 TS 0.07000

THE MOLE FRACTION OF AR TS 0.94600

NO	PI	DRIFT	TREE	URLE	TALL	PS(ATM)
502	100.	7.29	1700.7	0.4505	174.0	5.4399
503	100.	7.53	1790.6	0.4602	22.2	5.2465
504	100.	7.63	1862.5	0.4663	85.1	6.2729
505	09.	7.85	1936.2	0.4732	27.9	6.5987
506	09.	7.12	1633.6	0.4037	287.0	5.0403
507	07.	7.34	1578.0	0.4382	309.0	4.7701
508	07.	7.34	1710.5	0.4523	123.0	5.3687
509	103.	6.01	1554.6	0.4352	553.0	4.8500
510	07.	6.82	1523.6	0.4325	737.0	4.4187
511	105.	7.00	1611.4	0.4415	507.0	5.1385
512	100.	7.66	1853.2	0.4654	87.0	6.2289
513	09.	7.12	1634.0	0.4030	184.0	5.0554
514	00.	7.29	1648.0	0.4502	127.0	5.3170

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Table III. Kinetic Scheme for Propene Oxidation

	A	12	$E_{\text{mole}}^{\text{kcal}}$	Ref
1) $\text{C}_3\text{H}_6 + \text{M} \rightleftharpoons \text{CH}_3 + \text{C}_2\text{H}_3 + \text{M}$	$5.4 \times 10^{75}$	-15.71	120	11
2) $\text{C}_3\text{H}_6 + \text{H} \rightleftharpoons \text{C}_3\text{H}_4 + \text{H}_2 + \text{H}$	$1.6 \times 10^{13}$		0	11
3) $\text{C}_3\text{H}_6 + \text{CH}_3 \rightleftharpoons \text{CH}_4 + \text{C}_3\text{H}_4 + \text{H}$	$2 \times 10^{13}$		14.0	13
4) $i\text{C}_3\text{H}_7 \rightleftharpoons \text{C}_3\text{H}_6 + \text{H}$	$2 \times 10^{14}$		41.3	11
5) $i\text{C}_3\text{H}_7 \rightleftharpoons \text{C}_2\text{H}_4 + \text{CH}_3$	$2 \times 10^7$		0.0	11
6) $\text{C}_3\text{H}_4 + \text{M} \rightleftharpoons \text{C}_3\text{H}_3 + \text{H} + \text{M}$	$2 \times 10^{17}$		65	11
7) $\text{C}_3\text{H}_4 + \text{H} \rightleftharpoons \text{C}_3\text{H}_3 + \text{H}_2$	$5 \times 10^{12}$		1.5	11
8) $\text{C}_3\text{H}_4 + \text{CH}_3 \rightleftharpoons \text{C}_3\text{H}_3 + \text{CH}_4$	$2 \times 10^{12}$		7.7	11
9) $\text{C}_3\text{H}_6 + \text{O}_2 \rightleftharpoons \text{CH}_3\text{CHO} + \text{CH}_2\text{O}$	$9.8 \times 10^{10}$	0.5	0.0	12
10) $\text{C}_3\text{H}_6 + \text{OH} \rightleftharpoons \text{CH}_3\text{CHO} + \text{CH}_3$	$8.1 \times 10^{10}$	0.5	1.0	12
11) $\text{C}_3\text{H}_6 + \text{O} \rightleftharpoons \text{C}_3\text{H}_4 + \text{H}_2\text{O}$	$8.1 \times 10^{11}$	0.5	0.0	12
12) $\text{O} + \text{C}_3\text{H}_6 \rightleftharpoons \text{CH}_2\text{O} + \text{C}_2\text{H}_4$	$1 \times 10^{13}$		0.0	3
13) $\text{C}_3\text{H}_4 + \text{O}_2 \rightleftharpoons \text{CH}_3\text{CO} + \text{HCO}$	$1.0 \times 10^{11}$	0.5	0.0	12
14) $\text{C}_3\text{H}_3 + \text{H}_2\text{O} \rightleftharpoons \text{OH} + \text{C}_3\text{H}_4$	$2.2 \times 10^{10}$	0.5	40	14
15) $\text{C}_3\text{H}_3 + \text{OH} \rightleftharpoons \text{O} + \text{C}_3\text{H}_4$	$2.8 \times 10^9$	0.5	27.9	14
16) $\text{C}_3\text{H}_2 + \text{OH} \rightleftharpoons \text{C}_3\text{H}_3 + \text{O}$	$7.8 \times 10^9$	0.5	26.5	14
17) $\text{C}_3\text{H}_2 + \text{H}_2\text{O} \rightleftharpoons \text{C}_3\text{H}_3 + \text{OH}$	$2.6 \times 10^{10}$	0.5	38.7	14
18) $\text{C}_3\text{H}_2 + \text{O} \rightleftharpoons \text{C}_2\text{H}_2 + \text{CO}$	$3 \times 10^{13}$			est 10
19) $\text{C}_3\text{H}_3 + \text{OH} \rightleftharpoons \text{C}_2\text{HO} + \text{CH}_3$	$2.6 \times 10^{10}$	0.5	15.5	14
20) $\text{C}_3\text{H}_2 + \text{OH} \rightleftharpoons \text{C}_2\text{H} + \text{CH}_2\text{O}$	$3 \times 10^{13}$			est 10

Table III (continued)

(21)	$C_2H + O_2 \rightleftharpoons CO + CHO$	$1 \times 10^{13}$		3.5	3
(22)	$CH_3CHO + OH \rightleftharpoons CH_3CO + H_2O$	$6.5 \times 10^{10}$	0.5	4.0	12
(23)	$CH_3CHO + H \rightleftharpoons CH_3CO + H_2$	$2.4 \times 10^{12}$	0.5	11.0	12
(24)	$CH_3CO + O \rightleftharpoons CH_3 + CO_2$	$6.1 \times 10^{11}$	0.5	-	12
(25)	$CH_3CO + O_2 \rightleftharpoons CH_2OH + CO_2$	$7.8 \times 10^{10}$	0.5	1.5	12
(26)	$CH_3CO + H \rightleftharpoons CH_3 + HCO$	$2.2 \times 10^{12}$	0.5	5.4	12
(27)	$CH_2OH + H \rightleftharpoons CH_3 + OH$	$2.2 \times 10^{12}$	0.5	10.7	12
(28)	$C_2H_4 + O \rightleftharpoons CH_3 + HCO$	$3 \times 10^{13}$	-	-	12
(29)	$C_2H_4 + O \rightleftharpoons C_2H_2 + H_2O$	$3 \times 10^{13}$	-	-	12
(30)	$C_2H_4 + OH \rightleftharpoons CH_3 + CH_2O$	$1 \times 10^{11}$	0.5	7.1	12
(31)	$C_2H + O_2 \rightleftharpoons CH + CO_2$	$1 \times 10^{14}$	-	23	12
(32)	$CH + O_2 \rightleftharpoons CO + OH$	$8.1 \times 10^{10}$	0.5	-	12
(33)	$C_2H_2 + OH \rightleftharpoons C_2H + H_2O$	$2.2 \times 10^{14}$	-	7	12
(34)	$C_2H_2 + O \rightleftharpoons C_2H + OH$	$3.4 \times 10^{15}$	-0.64	18.7	12
(35)	$CH_2O + M \rightleftharpoons H_2 + CO$	$2.1 \times 10^{16}$	-	35	12
(36)	$CH_2O + OH \rightleftharpoons HCO + H_2O$	$2 \times 10^{13}$	-	-	12
(37)	$HCO + M \rightleftharpoons H + CO$	$2 \times 10^{12}$	0.5	28.6	12
(38)	$O_2 + M \rightleftharpoons 2O$	$2.6 \times 10^{18}$	-1.0	118	12
(39)	$CO + O_2 \rightleftharpoons O + CO_2$	$1.6 \times 10^{13}$	-	41.1	12
(40)	$O + H_2 \rightleftharpoons OH + H$	$1.8 \times 10^{10}$	1.0	8.9	12
(41)	$H_2 + O_2 \rightleftharpoons 2OH$	$1.7 \times 10^{13}$	-	42.2	12

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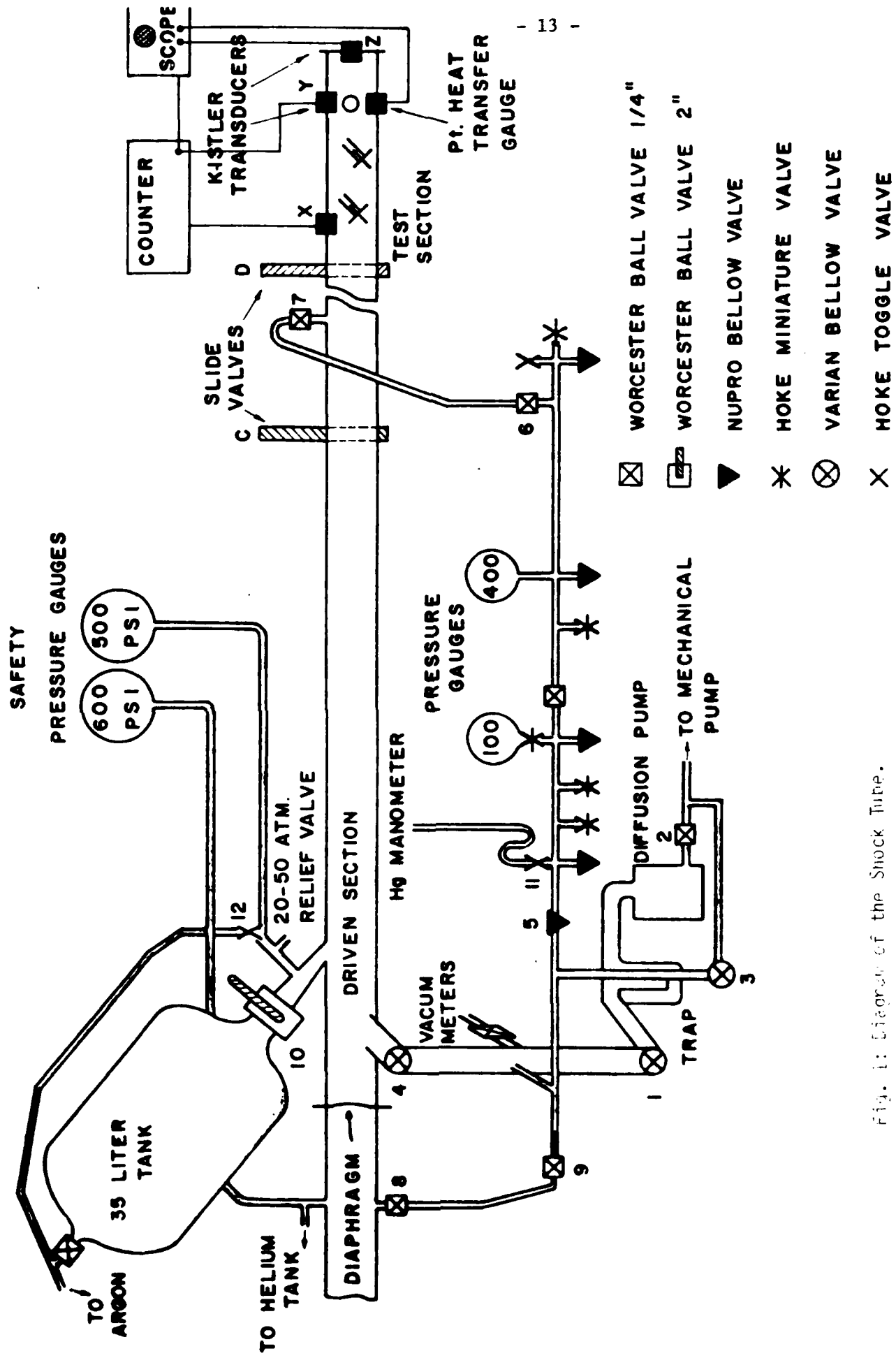


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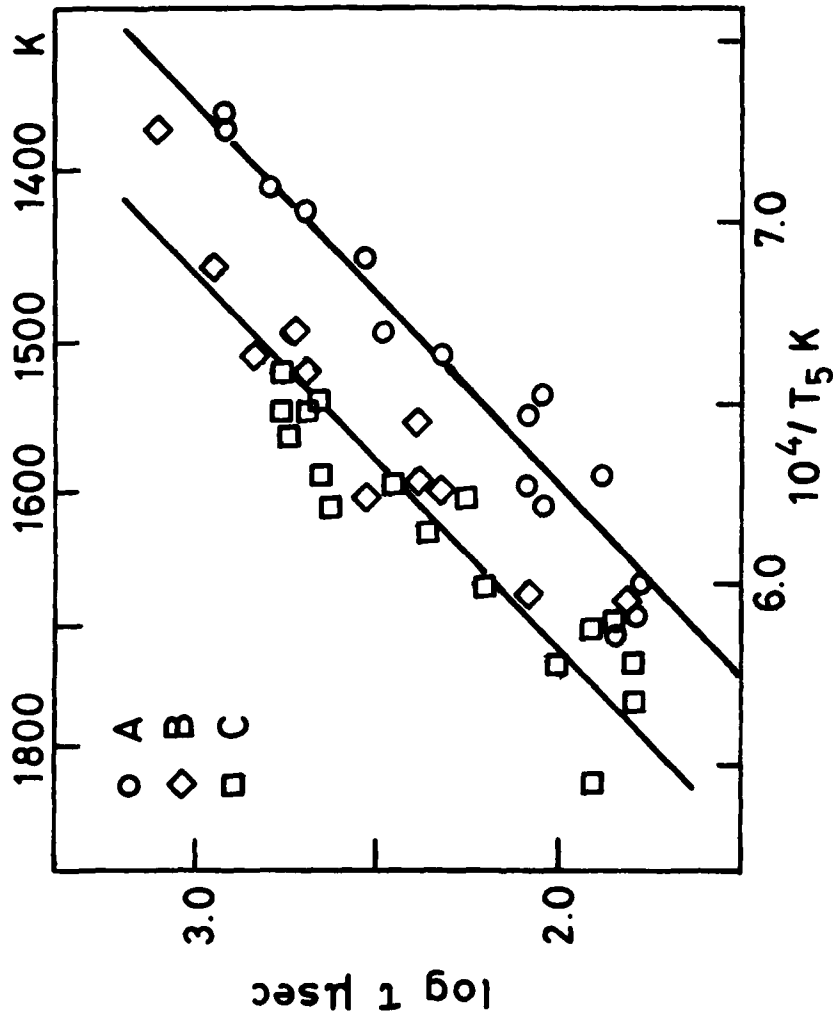


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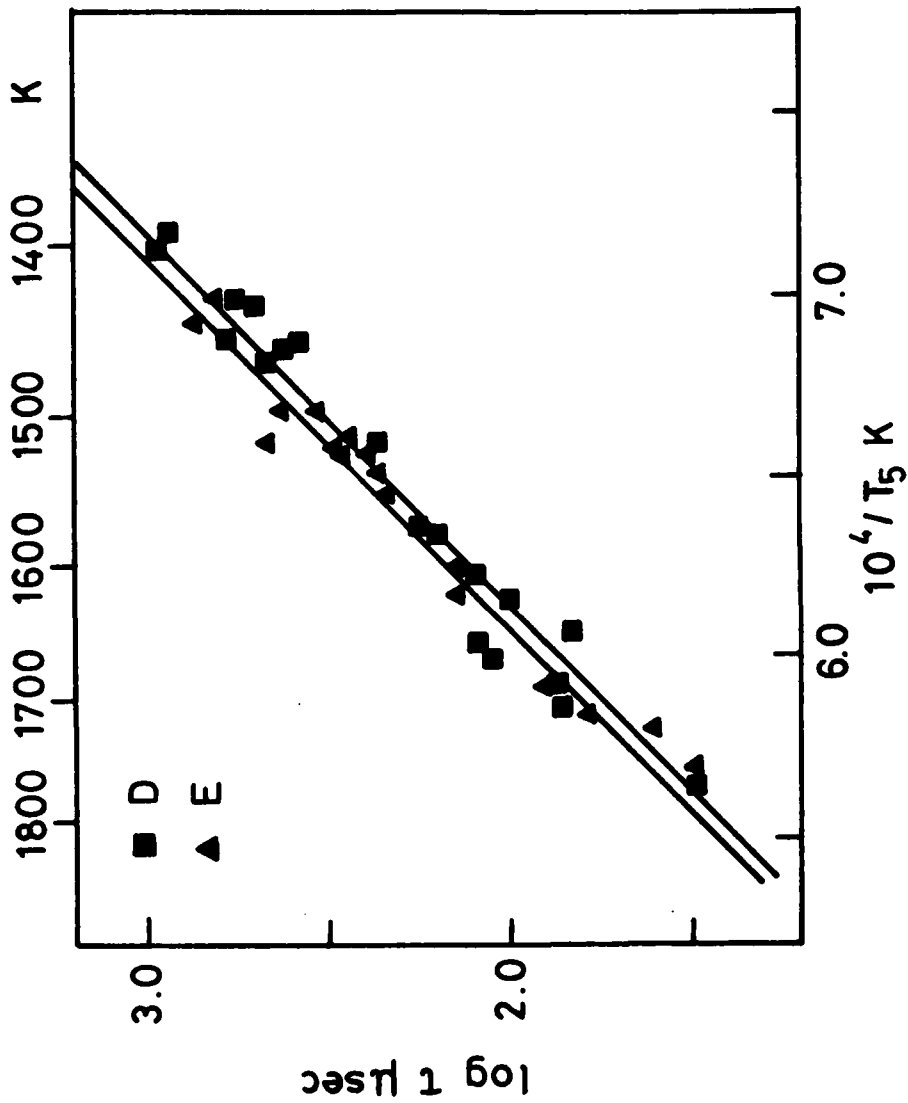


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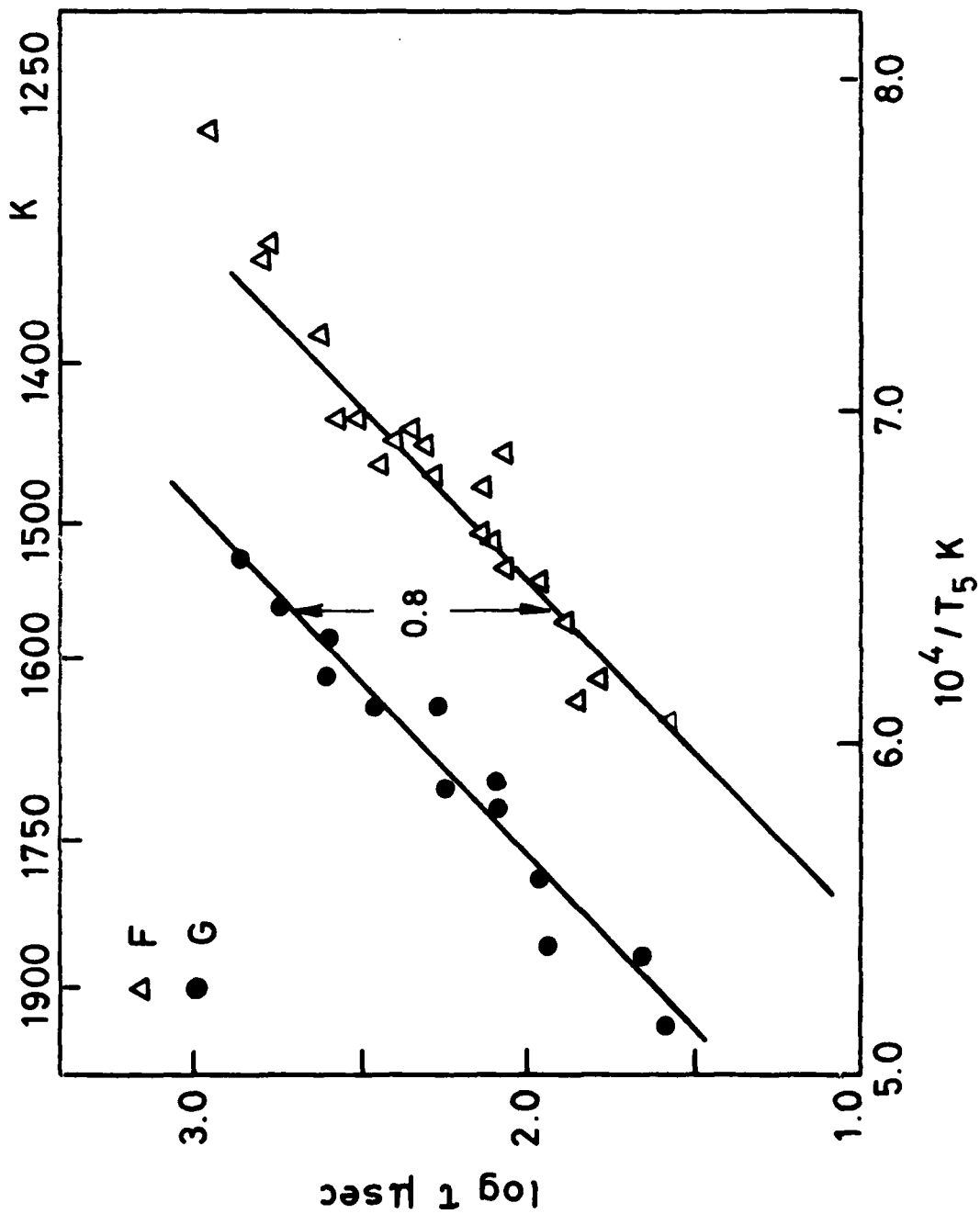


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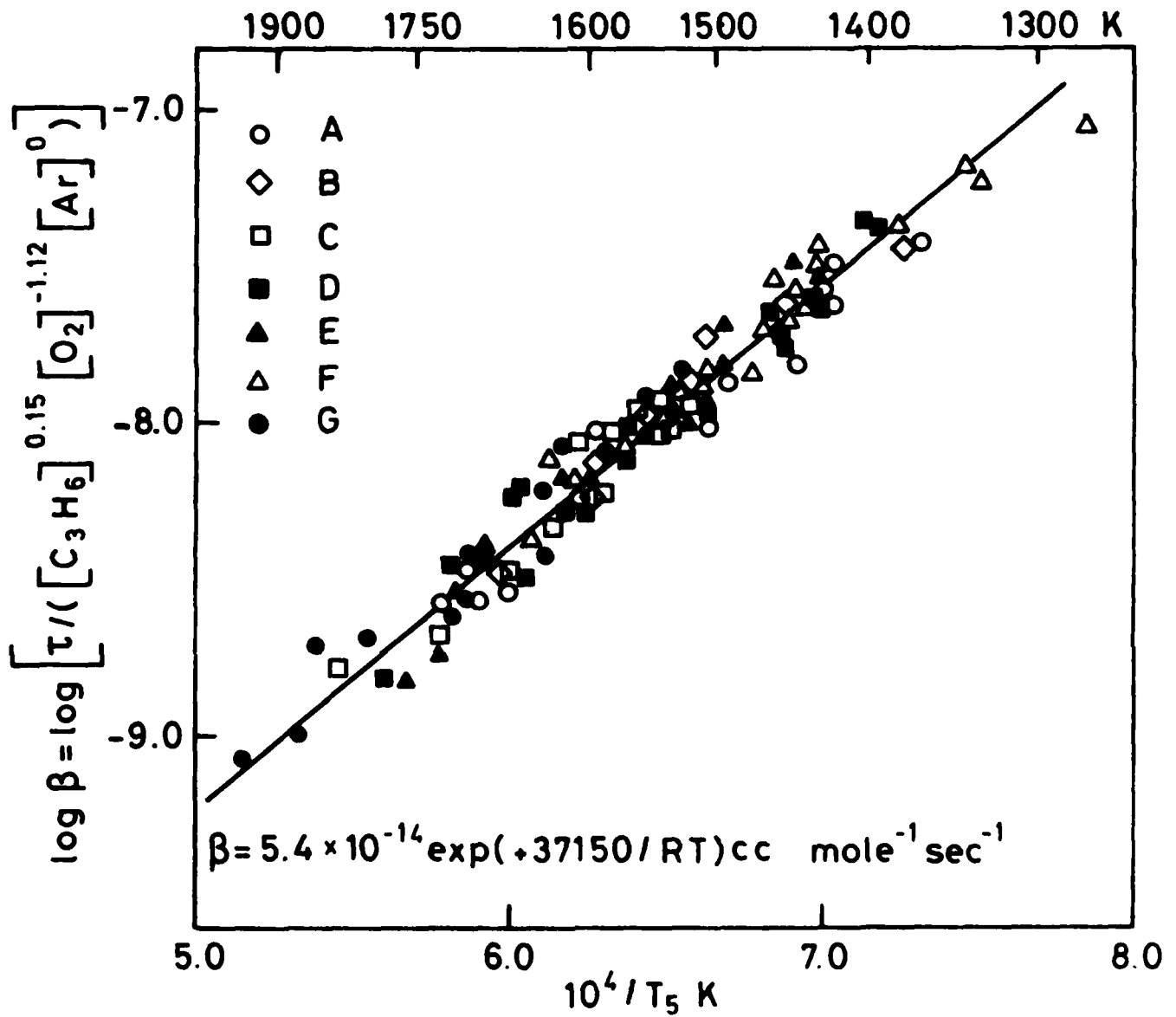


Fig. 5: A plot of  $\log \beta$  vs  $1/T_5$  for all the seven mixtures A to G. The maximum statistical spread allowed was 2%.

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