

# **Some Physical Chemistry Aspects of Thermite, Thermate, Iron-Aluminum-Rich Microspheres, the Eutectic, and the Iron-Sulfur System as Applied to the Demise of Three World Trade Center Buildings on 9/11/2001**

By  
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## **Acknowledgments**

I am indebted to Dr. Dale Huckaby of Texas Christian University and Dr. Richard Sisson of Worcester Polytechnic Institute for reference information pertaining to phase diagrams and to Dr. Frank Legge for critical review. However, the responsibility for this paper rests solely on me.

## **Introduction**

It has been established through a study of the photographic and video evidence that there were a number of instances of white-hot areas that produced glowing liquid flows from window openings on the 80<sup>th</sup> to 82<sup>nd</sup> floor of WTC 2 that persisted for quite a number of seconds. According to the NIST FAQ<sup>1</sup> these events came within the last 7 minutes before WTC 2 began its collapse. White-hot temperatures cannot be produced by ordinary fires. These observations have therefore been conclusively shown to be incendiary events. This fact is inconsistent with any theory of collapse except controlled demolition. Yet the official story remains that the buildings were brought down by fires and damage to the structural members of the buildings resulting from the impact of the planes. The WTC 7 wasn't even hit by a plane, yet it is claimed that it was brought down by fires.

All three buildings, WTC 1, WTC 2 and WTC 7 were subjects of many video documents that remain today as some of the very best evidence for controlled demolition that we have. It is clear from the videos that explosives were used. The evidence for incendiary cutting of steel consists of the video evidence, the forensic evidence in the dust and rubble, and the testimony of eyewitness early responders and survivors who saw glowing molten metal flowing out of window openings.

This paper deals with the incendiary events and the forensic evidence that remains to prove that the official story is wrong. Specifically, this paper discusses the chemistry of iron-aluminum-rich microspheres that are found in the dust from the rubble, the chemical content of these microspheres and the physical chemistry of the iron-sulfur-oxygen system since sulfur is one of the omnipresent elements in the iron-aluminum-rich microspheres and was also found in a metallurgical study of structural iron from the WTC 7<sup>2</sup>.

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<sup>1</sup> [http://wtc.nist.gov/pubs/factsheets/faqs\\_8\\_2006.htm](http://wtc.nist.gov/pubs/factsheets/faqs_8_2006.htm),

<sup>2</sup> [http://911research.wtc7.net/wtc/evidence/metallurgy/WTC\\_apndxC.htm](http://911research.wtc7.net/wtc/evidence/metallurgy/WTC_apndxC.htm), by Jonathan Barnett, Ronald R. Biederman, R. D. Sisson, Jr. of Worcester Polytechnic Institute

Dr. Steven Jones discovered the iron-aluminum-rich microspheres and has analyzed their elemental composition using XEDS analysis.<sup>3</sup> This discovery, of recent date, is a very important addition to the body of evidence that disproves the official story. At the present time the interpretation of these microspheres is still under discussion as is the composition of the incendiary they imply.

This paper brings the subject of physical chemistry into the investigation and suggests some new possibilities that should be considered to enhance the scientific basis of the claim that incendiary devices were employed in the demolition of the WTC buildings.

Physical chemistry is a subject that bridges physics and chemistry. It involves the study of the interactions between matter and energy. Whereas chemistry is concerned primarily with the material changes that occur in reactions, and physics may be regarded as a study of energy and its transformations, physical chemistry is concerned with both of these subjects. The influence of physical factors such as temperature, pressure, concentration, electricity, and light, both on the reacting substances and the reactions is studied in physical chemistry to better understand the fundamental nature of chemical change. The thermodynamics of changes in matter is an area we will discuss in this paper in connection with 9/11. We will also be interested in surface tension.

It is important that an alternate theory of the demise of the WTC towers be consistent with physical chemistry principles, and it is to that end that this paper is dedicated.

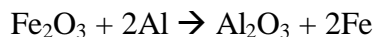
### **About Thermite**

The evidence is overwhelming that thermite or a thermite-like mixture was used in the WTC 2 tower very shortly before the building fell. What was the purpose of this? Thermite has been used to weld railroad rail sections together and also to cut structural steel. It has also been used for military purposes such as destroying guns and other weapons, disabling engines, and to rapidly destroy cryptographic machines. It appears that in the WTC it was used to cut structural steel in an early phase of controlled demolition.

This use implies that whatever the task, it had to be completed in the last minute or so before the building began to fall. Any chemical process that continued after the primary task was completed is simply an unavoidable sequela of the primary purpose.

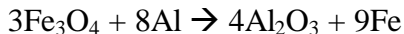
An excellent article on thermite is posted in wikipedia at <http://en.wikipedia.org/wiki/Thermite#Types>.

There are a number of possible reactions that could produce large amounts of heat that could be used to melt (cut) steel. For example,



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<sup>3</sup> "Revisiting 9/11/2001—Applying the Scientific Method", by Dr. Steven Jones, Journal of 911 Studies, V 11, May 2007



These reactions all produce a free metal and release a large quantity of heat that leaves a residue of very hot molten metal. It is not the purpose of this paper to analyze each of these reactions (and others) that could be used to cut structural steel. We are not interested here in comparing the relative merits of these reactions. We will restrict our attention to the first reaction and show how to determine how much thermite is needed to cut a given amount of structural steel.

One thing to notice about these equations is that they produce no gas that could be used to force the molten metal against the solid structural steel to be cut. That is a problem if vertical surfaces are to be cut (as in the WTC).

### **Engineering Considerations and the Use of Thermate**

Spectre Enterprises's patent for a linear pyrotechnic cutting device shows a stack of charge containers that are cylindrical with a slit nozzle in the wall parallel to the axis of the cylinder. The cylinder height is much smaller than the diameter. The molten liquid is forced out of the nozzle into contact with the steel object to be cut. This would seem to imply that there are additives in the charge that produce hot gas to provide the pressure to force out the liquid.<sup>4</sup> The gas is provided by an air filled empty space in the reaction chamber in the patent for Thermate-TH3<sup>5</sup>. Other methods of providing the required gas have also been used.

### **About Thermate**

When sulfur is added to thermite the result is called thermate. Other reaction enhancing chemicals may also be added. Thermate is said to have superior steel cutting capabilities compared with thermite for reasons that have not yet been fully explained. In this section we will discuss what is known about the properties of thermate that may have some bearing on its cutting properties.

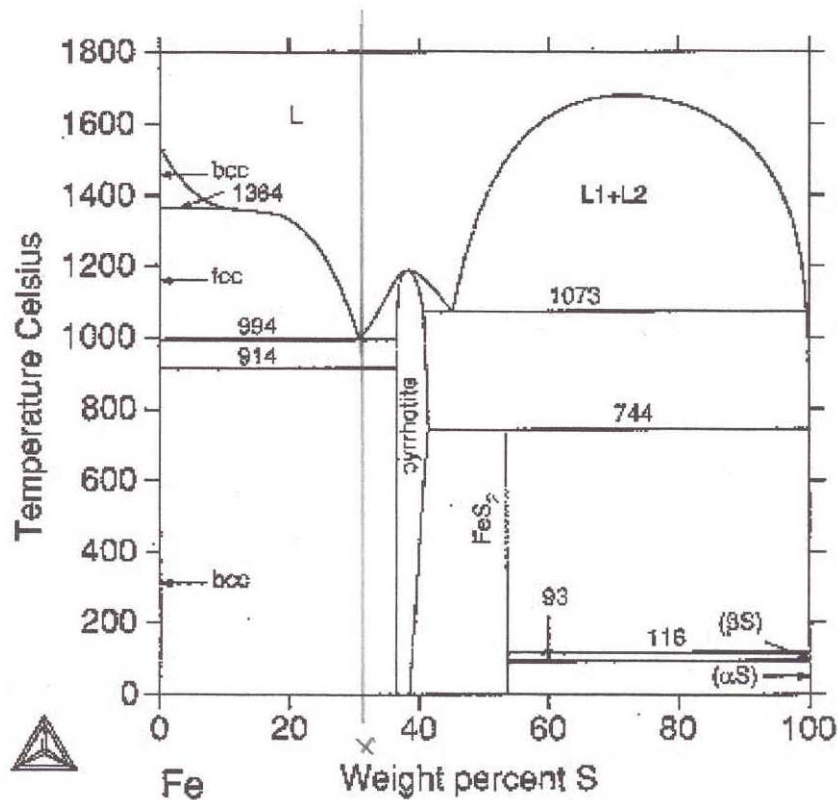
### **What does the addition of sulfur do?**

Ignition of thermite causes the reaction mix to be heated to white-hot temperatures (~ 2500 C). Monoclinic sulfur melts at 119.25 C and boils at 444.6 C. However, sulfur and iron are miscible, and research has shown that the Fe-S binary system at one atmosphere of pressure forms a liquid at temperatures as high as 1800 C, far above the boiling point of sulfur alone. The phase behavior of this system has been studied extensively. Figure 1 is the phase diagram of the Fe-S system at 1 atmosphere of pressure.

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<sup>4</sup> "Thermite mixtures of metals and fuels such as aluminum, zirconium, magnesium, boron or titanium; oxides such as iron oxide, common chemical oxidizers such as nitrates and perchlorates, halogen containing polymers and other gas producing materials, such as fluorocarbon (e.g. polytetrafluoroethylene) are typical." From Patent detail, Spectre Enterprises. See post by Ferric Oxide, March 23, 2007 at <http://www.phpbbserver.com/stj911/viewtopic.php?mforum=stj911&t=50&postdays=0&postorder=asc&start=40&mforum=stj911>

<sup>5</sup> <http://www.dodtechmatch.com/DOD/Patent/PatentDetail.aspx?type=description&id=6766744>



**Figure 1—Phase Diagram, Fe-S Binary System**

For our purposes we consider Fe-S mixtures that contain 31.4% by weight sulfur (the point x in Figure 1) or less. At 31.4% sulfur and 994 C<sup>6</sup> the system is at the eutectic point; i.e., the lowest temperature at which liquid can exist in a mixture of S and Fe.

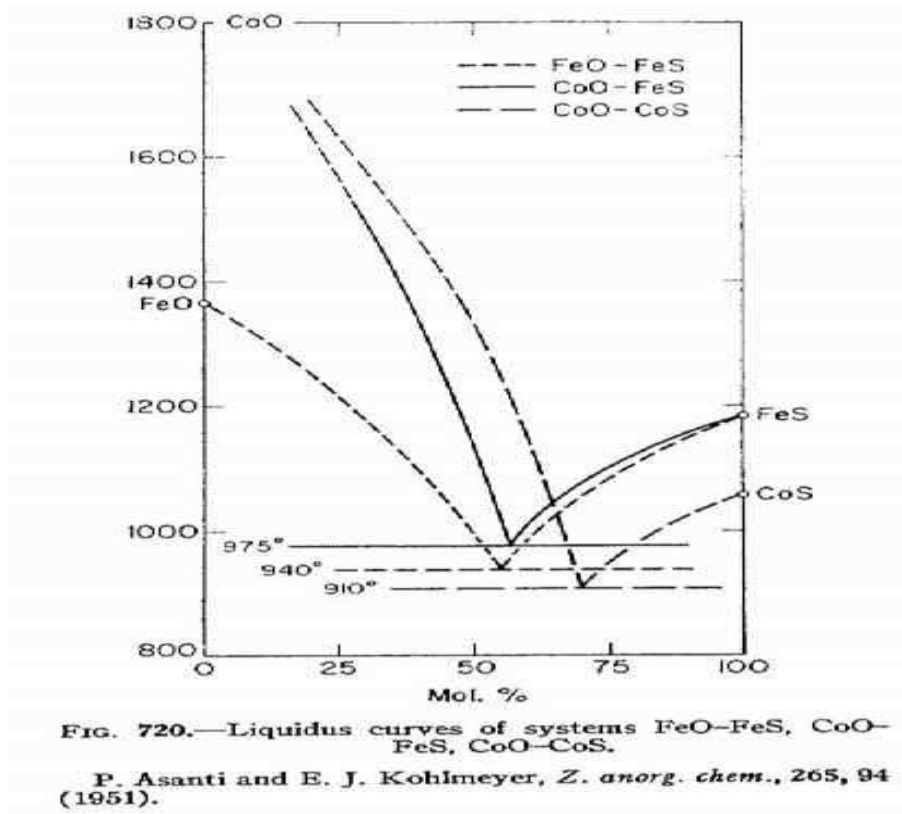
In the liquid state the mixture (at any concentration) is homogeneous. However, the solid state is heterogeneous and the character of its heterogeneity at any given concentration may be dependent on the history of its solidification process. Certain domains of the solid mixture in the phase diagram are characterized by different crystal structures. Figure 1 assumes that no other elements are in contact with the Fe-S system. If there is any space above the surface of the mix in the closed system that space will contain gaseous sulfur.

A complication occurs if the system is open to the air. In that case we have a ternary system, Fe-S-O. This was the case in the WTC situation. Of course, oxygen is a diatomic gas, O<sub>2</sub>, at all temperatures of interest here. Solid sulfur will ignite rather easily in air. Its flash point is 207.2 C, and its self ignition point is 237.2 C. So our system contains solid, liquid, and gaseous phases. We have not only a ternary system, but one which forms compounds, FeO and FeS under various conditions of temperature and concentrations of Fe, S, and O. And we know that FeO and FeS form a binary eutectic system<sup>7</sup>, so that it is possible to have heterogeneous mixtures

<sup>6</sup> Other measurement data shows a eutectic temperature of 988 C. The exact value is not critical for our discussion.

<sup>7</sup> Thanks to Dr. Richard D. Sisson, Jr. for this information.

of solid FeS, FeO, Fe, and S. The phase diagram for FeO and FeS is given in Figure 2. The temperature scale is Celsius.



**Figure 2-- FeO-FeS Phase Diagram**

A further complication is the fact that FeO and FeS are non-stoichiometric compounds. That is, they do not contain exactly as many atoms of one element as they do of the other. This means that the crystal structure is not regular, but has unpredictable irregularities that cause granularity. There can be interfacial areas that are cationic and others that are anionic, contributing to corrosion of Fe over time. The corrosion rates are unknown.<sup>8</sup>

One must also consider time scales for phase transformations in an environment where temperature gradients are severe and heat is conducted rapidly. The phase diagrams depict equilibrium states, and we have already noted that the heterogeneous structure of the solid that results upon cooling when ambient temperature is reached may depend on the rapidity of cooling.

The efficiency of cutting steel depends on effective heat transfer as well. We know empirically that when a white-hot liquid thermate reaction mixture is sprayed from a nozzle against steel at

<sup>8</sup> See Footnote 2, Barnett, Biederman, and Sisson

room temperature it cuts through the steel more easily than does reacting thermite that is simply in contact with the steel.

In addition to sulfur, other chemicals such as  $\text{Ba}(\text{NO}_3)_2$  may be added. It is said that the reaction is speeded up as a result of adding  $\text{KMnO}_4$ . These chemicals may decompose due to the heat and form compounds that may act as catalysts, not as a source of extra oxygen for, say, the purpose of providing gas for propelling the thermite mixture. A catalyst does not react in its role. It remains unchanged after the reaction has gone to completion.

The observations of Barnett, Biederman, and Sisson (BB&S) (See Footnote 2) describe sulfidation of some structural steel from WTC 7. They say:

“Rapid deterioration of the steel was a result of heating with oxidation in combination with intergranular melting due to the presence of sulfur. The formation of the eutectic mixture of iron oxide and iron sulfide lowers the temperature at which liquid can form in this steel. This strongly suggests that the temperatures in this region of the steel beam approached ~1000 C, forming the eutectic liquid by a process similar to making a “blacksmith’s weld” in a hand forge.”<sup>9</sup>

And they conclude:

“The severe corrosion and subsequent erosion of Samples 1 and 2<sup>10</sup> are a very unusual event. No clear explanation for the source of the sulfur has been identified. The rate of corrosion is also unknown. It is possible that this is the result of long-term heating in the ground following the collapse of the buildings. It is also possible that the phenomenon started prior to collapse and accelerated the weakening of the steel structure.”

We should take note of the fact that they are saying they have no idea of the rapidity of the sulfidation and oxidation processes or when they began. They also seem to be aware of the fact that there were large volumes of red hot metal below the rubble piles. (This is rather interesting since NIST, their sponsor, claims they are unaware of any such thing.)<sup>11</sup>

Now consider the problem of the molten metal flowing from the 82<sup>nd</sup> floor of WTC 2. Some have suggested that this metal was the eutectic mixture of Fe and S. Let’s discuss that possibility. We assume that the steel that is cut from the columns is essentially pure Fe. It is melted and mixes with the thermite reaction products and then flows away by gravity. As the mixture cools, if the original molten mix was at  $\text{S} < 31.4\%$ , Fe begins to crystallize out. This increases the S% in the remaining mix. As the cooling continues, the S% increases until it reaches 31.4%, and this remaining molten eutectic mixture solidifies at 994 C (or 988 C, depending on which measurement you believe). So unless the original S% was 31.4%, the molten mass is crystallizing out solidified Fe as it flows downhill and cools. When, in the cooling process, the molten mass reaches the eutectic composition, it also reaches the eutectic temperature. At that temperature the remaining liquid gives up its latent heat of fusion and crystallizes as a

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<sup>9</sup> See Footnote 2.

<sup>10</sup> From WTC 7 and WTC 1 or 2, respectively.

<sup>11</sup> John Gross, Video presentation at UT Austin, [http://www.pnacitizen.org/john\\_gross\\_nist\\_pnac.php](http://www.pnacitizen.org/john_gross_nist_pnac.php)

microscopically heterogeneous solid with a (macroscopically) 31.4% S, 68.6% Fe composition. Once all the material has solidified the entire mass resumes cooling. We thus have a plausible explanation of why the material flowing from WTC 2 was orange-hot liquid (~1000 C). However, if the thermate contained only 2% S by weight (as specified for Thermate-TH3)<sup>12</sup>, that would not be enough to even produce a eutectic mixture using all the Fe produced in the thermate reaction, let alone all the added Fe from the cut column. It is not likely that the amount of sulfur used would have produced a product close to the eutectic mixture; however any substantial amount of sulfur will usefully lower the melting point of the attacked steel by sulfidation.

### **About the iron-aluminum-rich microspheres**

Dr. Jones<sup>13</sup> found these microspheres in WTC dust that deposited in an apartment about 100 yards away from one of the towers. They contain Fe, Al, S, K, Mn and other elements in small percentages. Iron is a major component of these objects.

The spherical shape of the microspheres is caused by surface tension acting on tiny molten droplets. This is the only mechanism by which the spherical shape can be explained. Therefore, these microspheres are proof that molten iron was produced in the process that caused the demise of the WTC towers, a remarkable fact that does not fit the official story. Some of these microspheres are hollow, and Dr. Jones has determined that the inside surface of these spheres contain sulfur. This is consistent with a molten droplet containing some gaseous sulfur. The physics of this situation is the same as for bubbles. The surface tension and the internal gas pressure cause the radius of the bubble to adjust to balance these two forces.

### **Thermite Heat Balance Analysis**

It is all well and good to compare heats of reaction for various thermite analog reactions. But for purposes of cutting steel one needs to know how much thermite is needed to cut a particular size of steel column successfully. The cutting charge must melt the steel and heat the molten mass, including the reaction products, sufficiently to allow it to flow away from the cut before it solidifies. We cannot precisely determine how hot the molten mass must be through analysis, but we can determine the amount of thermite needed to heat the molten mass to its highest temperature. This analysis is useful for charge size estimation purposes.

I have computed the amount of steel that can be cut away per gram of Fe<sub>3</sub>O<sub>4</sub>-Al thermite given a desired final temperature of the molten mix. This is done using chemical engineering thermodynamics methods.

In doing the heat balance I assume that all quantities are in stoichiometric proportions. I also assume that the heat of reaction is consumed in heating all the products of the reaction at 100% efficiency.

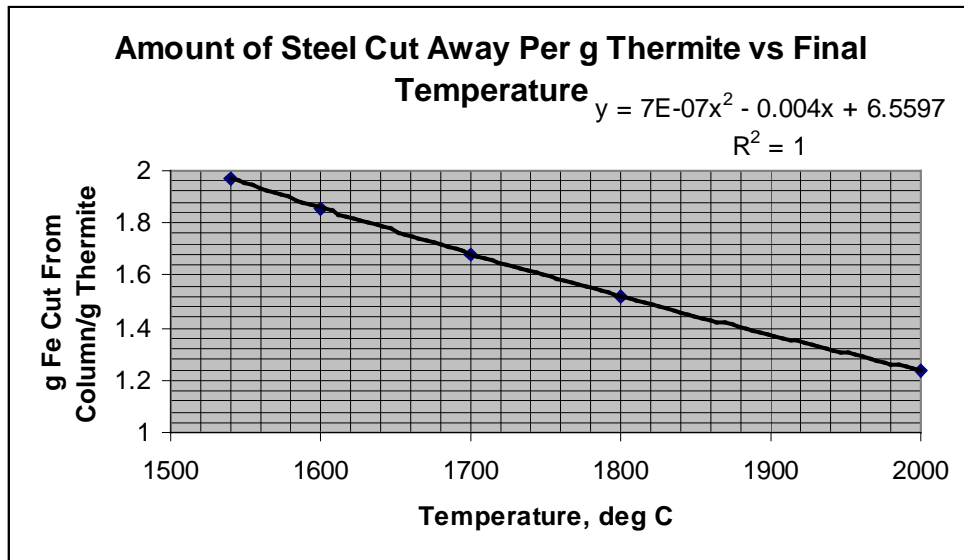
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<sup>12</sup> See Footnote 5.

<sup>13</sup> See Footnote 3

The calculations and data for this heat balance are a bit complicated and have been relegated to the Appendix. Figure 3 gives the results of the heat balance calculations.

The higher the maximum temperature reached by the molten mix, the longer it will remain molten as it flows away from the cut. But we pay a price to increase that maximum temperature. Addition of sulfur decreases the temperature at which the molten mix solidifies and increases the time available for the molten mix to flow away from the cut. Adding sulfur would decrease the required maximum temperature, and thus, decrease the amount of thermite needed to do a particular job. Only experimentation can determine what the optimum proportion of sulfur would be to minimize the amount of thermite needed to accomplish the desired cut.



**Figure 3—Amount of Steel Cut Away Per g of Thermite vs Final Temperature of the Molten Mix**



## **Conclusions**

This paper has discussed some physical chemistry aspects of thermite and thermate and shown how science explains the existence of iron-aluminum-rich microspheres, why some microspheres are hollow, and why the metallurgical forensic study produced the results it did. The thermodynamic analysis has provided an understanding of how much thermite is needed to cut away a given amount of steel at 100% efficiency. The complexity of the chemistry involved has been illuminated.

These analyses enhance our understanding of the evidence that proves the use of incendiary devices in demolition of the WTC buildings.

## APPENDIX A

**Table A-1—Chemical Data Used in Heat Balance Calculations**

Heat of Reaction, cal/g mole	203513.384	cal/gram-mole
cal/Joule	0.239005736	( <a href="http://www.onlineconversion.com/energy.htm">http://www.onlineconversion.com/energy.htm</a> )
Cp of Fe	Equation 1	cal/K/gram-mole
Cp of S/g	Equation 2	cal/K/gram-mole
Cp of Al <sub>2</sub> O <sub>3</sub> /g	Equation 3	cal/K/gram-mole
Heat of Fusion, Fe	59.09882213	cal/g
Heat of Fusion, S	9.2	cal/g 115.21, wiki temp, CRC 78th Ed. <a href="http://www.speclab.com/elements/sulfur.htm">http://www.speclab.com/elements/sulfur.htm</a>
Heat of vaporization, Fe	340	kJ/mole, <a href="http://en.wikipedia.org/wiki/Iron">http://en.wikipedia.org/wiki/Iron</a>
Heat of vaporization, Fe cal/g	1455.003586	cal/g
Heat of vaporization, S cal/g	335.4100333	cal/g, 444.6 C
Heat of Transition (rhombic--> monoclinic)	2.900268197	cal/g (at 94.9 C)
To	25	degC
At Wt Fe	55.85	
At Wt Al	26.98	
At Wt S	32.066	
M P S (rhomb)	112.8	deg C
M P S (monoclinic)	119.25	deg C
M P S (wiki) (not used)	115.21	deg C
B P S	444.6	deg C
M P Fe	1538	deg C
B P Fe	3000	deg C
Mol Wt Fe <sub>2</sub> O <sub>3</sub>	159.7	g
Mol Wt Al <sub>2</sub> O <sub>3</sub>	101.96	g

**Equation 1: (Fe)** (Source 2 p. 221)

4.13 + 0.00638T	T = 273 to 1041 K	Crystalline, $\alpha$
6.12 + 0.00336T	T = 1041 to 1179	Crystalline, $\beta$
8.4	T = 1179 to 1674	Crystalline, $\gamma$
10.0	T = 1674 to 1811 <sup>A-1</sup>	Crystalline, $\delta$
8.15	T = 1811 to 1873	Liquid
8.15	T = 1873 to 2773	Liquid (assumed)

**Equation 2: (S)** (Source 2 p. 224)

3.63 + 0.00640T	T = 273 to 368 K	Crystalline, rhombic
4.38 + 0.00440T	T = 368 to 392.35	Crystalline, monoclinic
(Unknown)	T = 392.35 to 717.7	Liquid
(Unknown)	T = 717.7 to 2773	gas

<sup>A-1</sup> Chemical Engineers' Handbook shows 1803 K. Accepted value of Fe melting point is 1811 K (2007)

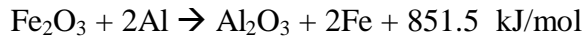
**Equation 3: (Al<sub>2</sub>O<sub>3</sub>)** (Source 2 p. 219)

$22.08 + 0.008971T - 522500/T^2$	T = 273 to 1973	Crystalline
(Unknown)	T = 1973 to 2773	Crystalline

**Sources:**

1. Handbook of Chemistry and Physics, 39<sup>th</sup> Ed., 1957, 78<sup>th</sup> Ed., 1996
2. Chemical Engineers' Handbook, 3<sup>rd</sup> Ed., 1950 and 6<sup>th</sup> Ed., 1984
3. Introduction to Chemical Engineering Thermodynamics, by J. M. Smith, McGraw-Hill 1949

**Thermite Heat Balance**



The yield for stoichiometric quantities is summarized in Table A-2.

**Table A-2—Mass of Reaction Products per Gram of Thermite**

Chemical	N moles	g/mole	g (molar portions)	For 1 g thermite	
				g	% of molar
Fe <sub>2</sub> O <sub>3</sub>	1	159.7	159.7	0.7474	0.47%
Al	2	26.98	53.96	0.2526	0.47%
Al <sub>2</sub> O <sub>3</sub>	1	101.96	101.96	0.4772	0.47%
Fe	2	55.85	111.7	0.5228	0.47%

**Heat of Reaction**

Thermite is formulated as  $159.7/53.96 = 2.960$  parts Fe<sub>2</sub>O<sub>3</sub> to 1 part Al (by weight). If 159.7 g of Fe<sub>2</sub>O<sub>3</sub> is used, 851.5 kJ is liberated. If 0.7474 g of Fe<sub>2</sub>O<sub>3</sub> is used, then  $0.0047 \cdot 851.5$  kJ is liberated. Converting kJ to cal, multiply by 239.0057. So, 0.7474 g of Fe<sub>2</sub>O<sub>3</sub> (1 g thermite) produces 956.51 cal of reaction heat.

**Problem A-1**

When thermite reacts, if there is no excess Fe in contact with the molten reaction product, the reaction heat will be used up to heat only the reaction products. However, we want to produce molten Fe from not only the thermite, but also from the cutting of the structural steel column. How much structural steel liquid could be produced at, say, 1800 C per gram of thermite?

**Solution**

The reaction must heat the reaction products from a reference temperature of 25 C to 1800 C and melt X grams of structural steel whose original temperature is 25 C into molten Fe at 1800 C. Since the Fe is being transformed from the solid state at 25 C into the liquid state at 1800 C the heat of fusion of Fe at 59.1 cal/g, must be added to convert the Fe from solid to liquid. The Al<sub>2</sub>O<sub>3</sub>

remains in the same crystalline state throughout the process, so it has no heat of transition component as the reaction products and the molten Fe from the cutting operation come to equilibrium at 1800 C.

The enthalpy of the nth component due to temperature change,  $\Delta H_T(n)$ , depends on the mass, m, of the component, the heat capacity per gram,  $c_p$ , of the component, and the temperature difference,  $(T_2 - T_1)$ . The equation is

$$\Delta H_T(n) = m(n) c_p(n)(T_2 - T_1) \quad \text{A-1}$$

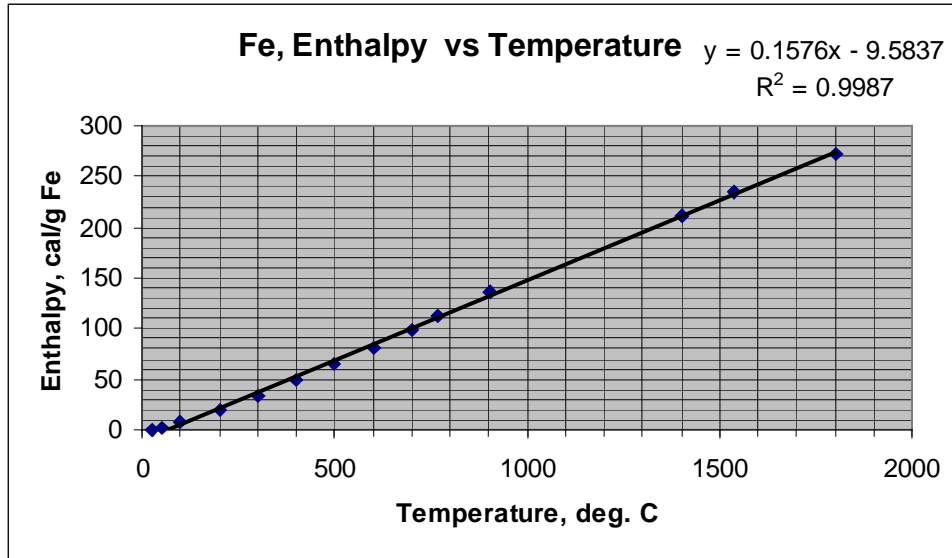
**Table A-3 – Heat absorbed by Reaction Product Fe**

**Fe**

T (deg C)	T (deg K)	Cp, cal/deg/g-mol	cp, cal/deg/g	$\Delta H$ , cal/g	H cal/g
25	298.1	6.032	0.1080		0.0000
50	323.1	6.191	0.1109	2.7357	2.7357
100	373.1	6.510	0.1166	5.6857	8.4214
200	473.1	7.148	0.1280	12.2281	20.6495
300	573.1	7.786	0.1394	13.3704	34.0199
400	673.1	8.424	0.1508	14.5128	48.5326
500	773.1	9.062	0.1623	15.6551	64.1877
600	873.1	9.700	0.1737	16.7975	80.9852
700	973.1	10.338	0.1851	17.9398	98.9250
767.9	1041	10.772	0.1929	12.8323	111.7573
767.90001	1041	9.618	0.1722	0.0000	111.7573
905.9	1179	10.081	0.1805	24.3374	136.0947
905.90001	1179	8.400	0.1504	0.0000	136.0947
1400.9	1674	8.400	0.1504	74.4494	210.5441
1400.9	1674	10.000	0.1791	0.0000	210.5441
1537.9	1811	10.000	0.1791	24.5300	235.0741
1537.9	1811	8.150	0.1459	0.0000	235.0741
1800	2073.1	8.150	0.1459	38.2474	273.3215

<b>cal/g Fe</b>	<b>273.3215cal/g Fe</b>
<b>Heat of Fusion Fe</b>	<b>59.0988cal/g Fe</b>
<b>g Fe/g Thermite</b>	<b>0.5228</b>
<b>cal/g thermite</b>	<b>173.7893</b>

NOTE: The heats of transition from  $\alpha \rightarrow \beta \rightarrow \gamma \rightarrow \delta$  crystalline forms are assumed to be zero in the absence of data. This assumption probably introduces only a very small error.



**Figure A-1 –Curve fit of Enthalpy vs Temperature, Fe**

Table A-4 -- Heat absorbed by Reaction Product Al<sub>2</sub>O<sub>3</sub>

## Al<sub>2</sub>O<sub>3</sub>

T (deg C)	T (deg K)	Cp, cal/deg/g-mol	cp, cal/deg/g	ΔH, cal/g	H
25	298.1	18.8745	0.1851		0.0000
107	380.1	21.8734	0.2145	16.3855	16.3855
214	487.1	24.2476	0.2378	24.2004	40.5858
321	594.1	25.9293	0.2543	26.3286	66.9145
428	701.1	27.3066	0.2678	27.9337	94.8482
535	808.1	28.5293	0.2798	29.2980	124.1461
642	915.1	29.6654	0.2910	30.5357	154.6818
749	1022.1	30.7491	0.3016	31.7004	186.3823
856	1129.1	31.7993	0.3119	32.8201	219.2024
963	1236.1	32.8271	0.3220	33.9105	253.1129
1070	1343.1	33.8393	0.3319	34.9809	288.0938
1177	1450.1	34.8404	0.3417	36.0373	324.1311
1284	1557.1	35.8332	0.3514	37.0835	361.2146
1391	1664.1	36.8200	0.3611	38.1223	399.3369
1498	1771.1	37.8020	0.3708	39.1553	438.4922
1605	1878.1	38.7803	0.3803	40.1839	478.6761
1712	1985.1	39.7557	0.3899	41.2091	519.8852
1800	2073.1	40.5562	0.3978	34.6580	554.5431

554.5431 cal/g Al<sub>2</sub>O<sub>3</sub>

g Al<sub>2</sub>O<sub>3</sub>/g Thermite      0.4772  
 cal/g thermite            264.6280

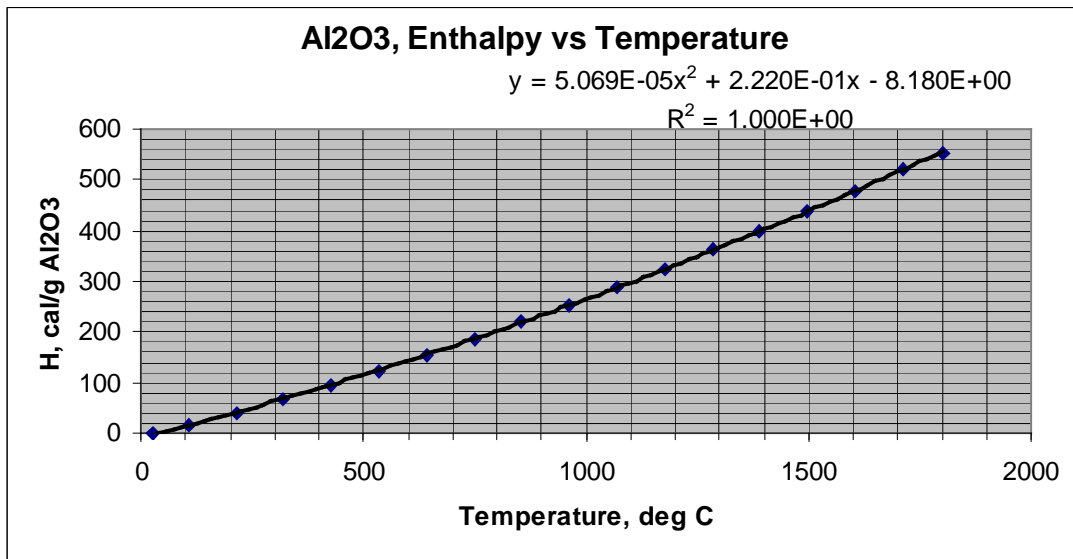


Figure A-2 –Curve fit of Enthalpy vs Temperature, Al<sub>2</sub>O<sub>3</sub>

From Tables A-3, A-4 the total heat absorbed by reaction products in mix that ends up at 1800 C is  $173.789 + 264.628 = 438.417$  cal. This leaves  $952.51 - 438.417 = 514.093$  cal to heat X g of Fe from the cutting of structural steel.

From Table A-3,  $273.321 + 59.1 = 332.421$  cal/g Fe is required to heat it from 25 C to 1800 C. Since we have 514.093 calories available,  $X = 514.093/332.421 = 1.547$  g structural steel/g thermite roughly. Again, this is a little optimistic since we do not have heats of transition for the different crystalline forms of Fe.

Now we do Problem A-1 for final temperatures between 1540 C and 2000 C using the curve fit equations given in Figures A-1 and A-2. These data are plotted in Figure 3.

**Table A-5— Grams of Steel Cut Away per Gram of Thermite vs Final Temperature (For Figure 3)**

Heat of Reaction/g thermite = 952.51 cal  
 g Fe/g thermite = 0.5228  
 g Al<sub>2</sub>O<sub>3</sub>/g thermite = 0.4772

T, deg C	H/g, Fe	H/g, Al <sub>2</sub> O <sub>3</sub>	H/g Thermite	H for column steel	g Fe from column
1540	230.35	453.92	367.93	584.58	2.02
1600	239.63	476.79	383.70	568.81	1.90
1700	255.11	515.71	410.37	542.14	1.73
1800	270.59	555.66	437.52	514.99	1.56
2000	301.55	638.58	493.28	459.23	1.27