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## Table of Contents

The Pedagogical Interrelationship Between Mathematics and Science Prince A. Jackson, Jr. ....	7
Educating Parents and Teachers for Intelligent Use and Support of Good Preschools Sadye A. Young .....	17
On Strengths of Shock Waves with Respect to Thermodynamic Parameters Nazir A. Warsi .....	35
Efforts to Prevent Negro Revolts in Early Savannah Austin D. Washington .....	39
White Professors and their Students in Southern Negro Colleges Carroll Atkinson .....	43
The Feasibility of Establishing a Library-College in Predominantly Negro Colleges Elonnie J. Josey .....	45
An Enrichment Program: Industrial Arts and Elementary Education Richard M. Coger .....	55
Far Infrared and Raman Studies on The O-H---O Bond Stretching Vibrations in Crystals Venkataraman Ananthanarayanan .....	60
The Distribution of Income in a Highly Industrialized Society Sarvan K. Bhatia .....	66
The Evolution of Free Enterprise and Capitalism in the United States Sarvan K. Bhatia .....	70
On Shock Strengths with Respect to Flow Parameters Nazir A. Warsi .....	75
Keats' <i>Endymion</i> : A Critical History Dennis A. Berthold .....	78
<i>Paradise Lost</i> and the Modern Reader: Five Approaches Dennis A. Berthold .....	89
A Design for Campus Libraries Based on the Favorite Study Habits and the Preferred Study Locations of Students at Fayetteville State College Charles I. Brown, Nathalie R. Smith, and Charles A. Asbury .....	100
Apartheid and Morality David S. Roberts .....	106
A Study of Psycho-Social Behavior of College Freshmen— 1966-67 Lawrence C. Bryant .....	109

## Table of Contents – (Cont'd.)

<i>Who's Afraid of Virginia Woolf?:</i> Some Factors that Generate and Sustain Dramatic Conflict Ollie Cox .....	114
Five Selected Poems Gershon B. Fiawoo .....	119
The Modern Dramatic Hero As Seen in the Plays of Brecht and Betti William T. Graves .....	124
Noah Webster as a Lexicographer William T. Graves .....	129
Whitman on Whitman: The Poet Introduces His Own Poetry Dennis A. Berthold .....	137
The Theory and Practice of Freedom David S. Roberts .....	143
The Nature of the Dispute Between Moscow and Peiping Liu Shia-ling .....	155
What Does it Matter to You? Samuel Williams .....	165
Ong, McLuhan, and the Function of the Literary Message Dennis A. Berthold .....	172
<i>In Vitro</i> Persistence of <i>Salmonella</i> Typhimurium in A Dually Inoculated Medium. I. With <i>Proteus Morgan II</i> Joseph L. Knuckles .....	177
<i>In Vitro</i> Persistence of <i>Salmonella</i> Typhimurium in A Dually Inoculated Medium. II. With <i>Aerobacter Cloacae</i> Joseph L. Knuckles .....	185
Experimental Transmission of Enteric Pathogens from Fly to Fly by Aseptically Reared <i>Phormia Regina</i> (Meigen) Joseph L. Knuckles .....	192
Mathematics in the Renaissance William M. Perel .....	193
Synthesis of Kaempferol-2-C <sup>14</sup> Kamalakar B. Raut .....	198
A Refutation to the Objections of Business and Vocational Subjects in the Secondary School Curriculum Mildred W. Glover .....	200
Teacher Personality and Teacher Behavior Shia-ling Liu .....	208
Poem: Epithalamia Luetta C. Milledge .....	222

# On Strengths of Shock Waves with Respect to Thermodynamic Parameters

by

Nazir A. Warsi

## 1. INTRODUCTION

If  $F$  is thermodynamic parameter, then the  $F$ -strength of a shock wave is given by

$$(1.1) \quad \delta_{F'} = [F]/F_{1/}$$

Hence, we define enthalpy, sound velocity, internal energy, temperature, entropy, and obliquity strengths of the shock wave by

$$(1.2) \quad \delta_{1'} = [I]/I_{1/},$$

$$(1.3) \quad \delta_{c^2'} = [c^2]/c_{1/}^2,$$

$$(1.4) \quad \delta_e = [e]/e_{1/},$$

$$(1.5) \quad \delta_{T'} = [T]/T_{1/},$$

$$(1.6) \quad \delta_{\eta'} = [\eta]/\eta_{1/},$$

and

$$(1.7) \quad \psi_{2/\alpha} = (1 + \delta_{\psi'})\psi_{1/\alpha},$$

respectively.

## 2. SHOCK STRENGTHS WITH RESPECT TO THERMODYNAMIC PARAMETERS

We have the following theorems in this connection.

Theorem 2.1:  $\delta_{\gamma'}$  and  $\delta_{1'}$  are related by

$$(2.1) \quad \delta_{1'} = \frac{-(\gamma - 1) h_{n'}^2 \delta_{\gamma'} (\delta_{\gamma'} + 2) \gamma_{1/}}{2\gamma p_{1/}}$$

or

$$(2.2) \quad \delta_{1'} = \frac{\gamma - 1}{2\gamma p} h_{n'}^2 \delta_{\gamma'} (\delta_{\gamma'} + 2) U_{1n'}.$$

*Proof:* The specific enthalpy behind a shock surface is given by [3]

$$(2.3) \quad [I] = -\frac{1}{2} h_{n'}^2 \delta_{\gamma'} (\delta_{\gamma'} + 2) \gamma_{1'}^2.$$

which, with the help of (1.2) and the relation  $I_{1/} = \frac{\gamma}{\gamma-1} p_{1/} \gamma_{1/}$ , gives (2.1). The equation (2.2) is easily obtained from (2.1) and the relation

$$- \dot{h}_{n/} \gamma_{1/} = U_{1n/}.$$

Theorem 2.2: *The value of  $\delta_{1/}$  is given by*

$$(2.4) \quad \delta_{1/} = \frac{-2 (\gamma - 1) \dot{h}_{n/} (C_{1/}^2 - \dot{h}_{1/}^2 \gamma_{1/}^2) (C_{1/}^2 + \gamma \dot{h}_{n/}^2 \gamma_{1/}^2)}{\gamma (\gamma + 1)^2 p_{1/} \dot{h}_{n/}^3 \gamma_{1/}^3}$$

*Proof:* We know that [1]

$$(2.5) \quad \delta_{\gamma/} = \frac{2 (C_{1/}^2 - \dot{h}_{n/}^2 \gamma_{1/}^2)}{(\gamma + 1) \dot{h}_{n/}^2 \gamma_{1/}^2}.$$

On substituting from (2.5) in (2.1), we get (2.4).

Theorem 2.3: *The sound velocity strength is the same as the specific enthalpy strength.*

*Proof:* For a polytropic gas, we have

$$(2.6) \quad I_{\alpha/} = \frac{\gamma}{\gamma - 1} C_{\alpha/}^2.$$

which easily gives

$$(2.7) \quad [I] = \frac{\gamma}{\gamma - 1} [C^2]$$

Equations (1.2) and (1.3) reduce (2.7) to

$$(2.8) \quad \delta_{1/} I_{1/} = \frac{\gamma}{\tau - 1} \delta c_{1/}^2 C_{1/}^2.$$

Now, (2.6) and (2.8) give

$$(2.9) \quad \delta_{1/} = \delta c_{1/}^2.$$

Theorem 2.4: *The internal energy and specific enthalpy strengths are the same.*

*Proof:* For a polytropic gas, we have

$$(2.10) \quad I_{\alpha/} = \frac{1}{\gamma} e_{\alpha/}.$$

This gives

$$(2.11) \quad [I] = \frac{1}{\gamma} [e]$$

On substituting the values of  $[I]$  and  $[e]$  from (1.2) and (1.4) respectively, (2.11) becomes

$$(2.12) \quad I_{1/} \delta_{1/} = \delta_{e/} \frac{e_{1/}}{\gamma}.$$

This, in virtue of (2.10), gives

$$(2.13) \quad \delta_{1/} = \delta_{e/}.$$

**Theorem 2.5:** *The temperature and specific enthalpy shock strengths are the same.*

*Proof:* For a polytropic gas, we have

$$(2.14) \quad I_{\alpha/} = \frac{\gamma}{\gamma - 1} R T_{\alpha/}.$$

which gives

$$(2.15) \quad [I] = \frac{\gamma}{\gamma - 1} R [T]$$

This equation, in virtue of (1.2), (1.5), and (2.14) becomes

$$(2.16) \quad \delta_{1/} = \delta_{T/}$$

**Theorem 2.6:** *The obliquity strength can be determined from*

$$(2.17) \quad \delta_{\psi/} = \frac{\dot{h}_{n/} \gamma_{1/} \delta_{\gamma/}}{U_{1n/} - \dot{h}_{n/} \gamma_{1/} \delta_{\gamma/}}$$

or

$$(2.18) \quad \delta_{\psi/} = \frac{-V_{in/} \delta_{\gamma/}}{U_{1n/} + V_{1n/} \delta_{\gamma/}}.$$

*Proof:* The equation (1.5) gives

$$(2.19) \quad \psi_{2/\alpha} = (\delta_{\psi/} + 1) \psi_{1/\alpha}.$$

Also, the components of obliquity in the region  $\beta/$  is given by [2]

$$(2.20) \quad \psi_{\beta/\alpha} = U_{\beta/1} X_{,\alpha}^1 / U_{\beta n/}.$$

which, for the region  $2/$ , becomes

$$(2.21) \quad \psi_{2/\alpha} = U_{2/1} X_{,\alpha}^1 / U_{2n/}.$$

Now, the normal velocity behind the shock surface is given [1]

$$(2.22) \quad [U_n] = \delta_{\gamma'} V_{1n'}.$$

Hence, (2.17) can be easily deduced from (2.19), (2.20), (2.21), and (2.22) by simple substitution. Equations (2.17) gives (2.18) with the help of the relation —  $\dot{h}_{n'} \gamma_{1'} = V_{1n'}$ .

Theorem 2.7: The entropy strength of the shock wave is given by

$$(2.23) \quad \delta_{n'} = \log \frac{(\delta_{\gamma'} + 1)^{\gamma-1}}{2 p_{1'} \gamma_{1'}^{\gamma} c_{1'}^2} \left\{ 2c_{1'}^2 - (\gamma - 1) \delta_{\gamma'} (\delta_{\gamma'} + 2) \dot{h}_{n'}^2 \gamma_{1'}^2 \right\}$$

*Proof:* The entropy behind a shock surface can be determined from [3]

$$(2.24) \quad [\eta] = J C_U \log \frac{(\delta_{\gamma'})^{\gamma-1}}{2 c_{1'}^2} \left\{ 2c_{1'}^2 - (\gamma - 1) \delta_{\gamma'} (\delta_{\gamma'} + 2) \dot{h}_{n'}^2 \gamma_{1'}^2 \right\}$$

This equation gives (2.23) on substitution from (1.6).

---

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# On Shock Strengths with Respect To Flow Parameters

by

Nazir A. Warsi

## 1. INTRODUCTION

The shock strength with respect to the specific volume  $\gamma$  is given by

$$(1.1) \quad \delta_{\gamma'} = [\gamma]/\gamma_{1'}$$

Similarly, the velocity and pressure shock strengths can be given by

$$(1.2) \quad \delta u_{n'} = [u_{n'}]/u_{1n'}$$

and

$$(1.3) \quad \delta_{p'} = [p]/p.$$

In what follows, an attempt has been made to find the relations between different parametric shock strengths.

## 2. DIFFERENT SHOCK STRENGTHS

We have the following theorems in this regard.

Theorem 2.1: For a given  $\delta_{\gamma'}$ , the velocity shock strength is given by

$$(2.1) \quad \delta u_{n'} = -\delta_{\gamma'} \dot{h}_{n'} \gamma_{1'}$$

or

$$(2.2) \quad \delta u_{n'} = \delta_{\gamma'} U_{1n'}/u_{1n'}$$

which, for a stationary shock, reduces to

$$(2.3) \quad \delta u_{n'} = \delta_{\gamma'}$$

*Proof:* The normal velocity behind the shock surface is given by [1]

$$(2.4) \quad [u_{n'}] = -\dot{h}_{n'} \delta_{\gamma'} \gamma_{1'}$$

or

$$(2.5) \quad [u_{n'}] = \delta_{\gamma'} v_{1n'}$$

Equations (2.4) and (2.5) together with (1.2) give (2.1) and (2.2) respectively. For a stationary shock surface,  $v_{1n'} = u_{1n'}$ . Thus, (2.2) reduces to (2.3).



Theorem 2.2: *The velocity strength of the shock is given by*

$$(2.6) \quad \delta_{un'} = \frac{-2}{\gamma + 1} \frac{c_{1'}^2 - \dot{h}_{n'}^2 \gamma_{1'}}{u_{1'n} - \dot{h}_{n'} \gamma_{1'}}$$

or

$$(2.7) \quad \delta_{un'} = \frac{-2}{\gamma + 1} \frac{\gamma p_{1'} - \dot{h}_{n'}^2 \gamma_{1'}}{\dot{h}_{n'} u_{1'n}}$$

or

$$(2.8) \quad \delta_{un'} = \frac{-2}{\gamma + 1} \frac{c_{1'}^2 - v_{1'n}^2}{v_{1'n} u_{1'n}}$$

or

$$(2.9) \quad \delta_{un'} = \frac{2}{\gamma + 1} \frac{\gamma p_{1'} + \dot{h}_{n'} v_{1'n}}{\dot{h}_{n'} u_{1'n}}$$

*Proof:* For the value of  $\delta_{\gamma'}$  we have [2]

$$(2.10) \quad \delta_{\gamma'} = \frac{2}{(\gamma + 1)} \frac{(c_{1'}^2 - \dot{h}_{n'}^2 \gamma_{1'}^2)}{\dot{h}_{n'}^2 \gamma_{1'}^2}$$

or

$$(2.11) \quad \delta_{\gamma_1} = \frac{2 (\gamma p_{1'} - \dot{h}_{n'}^2 \gamma_{1'})}{\gamma_{1'} \dot{h}_{n'}^2}$$

Substituting from these equations in (2.1) and (2.2), we get (2.6) and (2.7). Now, the relation  $-\dot{h}_{n'}^2 \gamma_{1'} = v_{1'n}$  reduces (2.6) and (2.7) to (2.8) and (2.9) respectively.

Theorem 2.3: *The pressure strength  $\delta_{p'}$  is related to  $\delta_{\gamma'}$  by*

$$(2.12) \quad \delta_{p'} = -\dot{h}_{n'}^2 \gamma_{1'} \delta_{\gamma_1} / p_{1'}$$

or

$$(2.13) \quad \delta_{p'} = \dot{h}_{n'} u_{1'n} \delta_{\gamma_1}$$

which, for a stationary shock reduces to

$$(2.14) \quad \delta_{p'} = \dot{h}_{n'} u_{1'n} \delta_{\gamma_1} / p_{1'}$$

*Proof:* The pressure behind the shock surface is given by [1]

$$(2.15) \quad [p] = h_{n/} \delta_{\gamma/} \gamma_{1/},$$

or

$$(2.16) \quad [p] = -\dot{h}_{n/} \delta_{\gamma/} v_{1n/}.$$

On substitution for  $[p]$  from (1.3), the equations (2.15) and (2.16) give (2.12) and (2.13) respectively. For a stationary shock,  $v_{1n/} = u_{1n/}$ . Hence, (2.13) gives (2.14) on application of this condition.

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