

LASER IGNITION OF ENERGETIC MATERIALS

S. RAFI AHMAD
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Laser Ignition of Energetic Materials

S Rafi Ahmad

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Contents

[About the Authors](#)

[Preface](#)

[Acknowledgements](#)

[Chapter 1: Historical Background](#)

[1.1 Introduction](#)

[1.2 The Gunpowder Era](#)

[1.3 Cannons, Muskets and Rockets](#)

[1.4 Explosive Warheads](#)

[1.5 Explosives Science](#)

[Bibliography](#)

[Chapter 2: Review of Laser Initiation](#)

[2.1 Introduction](#)

[2.2 Initiation Processes](#)

[2.3 Initiation by Direct Laser Irradiation](#)

[2.4 Laser-Driven Flyer Plate Initiations](#)

[2.5 Summary and Research Rationale](#)

[Bibliography](#)

[References](#)

[Chapter 3: Lasers and Their Characteristics](#)

[3.1 Definition of Laser](#)

[3.2 Concept of Light](#)

[3.3 Parameters Characterizing Light Sources](#)

[3.4 Basic Principle of Lasers](#)

[3.5 Basic Technology of Lasers](#)

[3.6 Comparison between Laser and Thermal Sources](#)

[3.7 Suitable Laser Sources for Ignition Applications](#)

[3.8 Beam Delivery Methods for Laser Ignition](#)

[3.9 Laser Safety](#)

[Bibliography](#)

[Chapter 4: General Characteristics of Energetic Materials](#)

[4.1 Introduction](#)

[4.2 The Nature of Explosions](#)

[4.3 Physical and Chemical Characteristics of Explosives](#)

[4.4 Fuel and Oxidizer Concept](#)

[4.5 Explosive Compounds](#)

[4.6 Thermodynamics of Explosions](#)

[Appendix 4.A](#)

[A.1 Data for Some Explosives](#)

[A.2 Unusual Explosives](#)

[Bibliography](#)

[Chapter 5: Recent Developments in Explosives](#)

[5.1 Introduction](#)

[5.2 Improvements in Explosive Performance](#)

[5.3 Areas under Development](#)

[5.4 Plastic-Bonded High Explosives](#)

[5.5 Choice of High Explosive for Plastic Bonded Compositions](#)

[5.6 High-Energy Plastic Matrices](#)

[5.7 Reduced Sensitivity Explosives](#)

[5.8 High Positive Enthalpies of Formation Explosives](#)

[Glossary of Chemical Names for High-Melting-Point Explosives](#)

[Bibliography](#)

[References](#)

[Chapter 6: Explosion Processes](#)

[6.1 Introduction](#)

[6.2 Burning](#)

[6.3 Detonation](#)

[6.4 Mechanism of Deflagration to Detonation Transition](#)

[6.5 Shock-to-Detonation](#)

[6.6 The Propagation of Detonation](#)

[6.7 Velocity of Detonation](#)

[6.8 The Measurement of Detonation Velocity](#)

[6.9 Classifications of Explosives and Pyrotechnics by Functions and Sensitivity](#)

[6.10 The Effects of High Explosives](#)

[6.11 Explosive Power](#)

[6.12 Calculation of Q and V from Thermochemistry of Explosives](#)

[6.13 Kistiakowsky - Wilson Rules](#)

[6.14 Additional Equilibria](#)

[6.15 Energy Released on Detonation](#)

[6.16 Volume of Gases Produced during Explosion](#)

[6.17 Explosive Power](#)

[6.18 Shockwave Effects](#)

[6.19 Appendices: Measurement of Velocity of Detonation](#)

[Appendix 6.A: Dautriche Method](#)

[Appendix 6.B: The Rotating Mirror Streak Camera Method](#)

[Appendix 6.C: The Continuous Wire Method](#)

[Appendix 6.D: The Event Circuit](#)

[Bibliography](#)

[References](#)

[Chapter 7: Decomposition Processes and Initiation of Energetic Materials](#)

[7.1 Effect of Heat on Explosives](#)

[7.2 Decomposition Mechanisms](#)

[7.3 Practical Initiation Techniques](#)

[7.4 Classification of Explosives by Ease of Initiation](#)

[7.5 Initiatory Explosives](#)

[7.6 Igniters and Detonators](#)

[7.7 Explosive Trains](#)

[Bibliography](#)

[References](#)

[Chapter 8: Developments in Alternative Primary Explosives](#)

[8.1 Safe Handling of Novel Primers](#)

[8.2 Introduction](#)

[8.3 Totally Organic](#)

[8.4 Simple Salts of Organics](#)

[8.5 Transition Metal Complexes and Salts](#)

[8.6 Enhancement of Laser Sensitivity](#)

[References](#)

[Appendix 8.A: Properties of Novel Primer Explosives](#)

[Appendix 8.B: Molecular Structures of Some New Primer Compounds](#)

[Chapter 9: Optical and Thermal Properties of Energetic Materials](#)

[9.1 Optical Properties](#)

[9.2 Thermal Properties](#)

[References](#)

[Chapter 10: Theoretical Aspects of Laser Interaction with Energetic Materials](#)

[10.1 Introduction](#)

[10.2 Parameters Relevant to Laser Interaction](#)

[10.3 Mathematical Formalism](#)

[10.4 Heat Transfer Theory](#)

[References](#)

[Chapter 11: Laser Ignition - Practical Considerations](#)

[11.1 Introduction](#)

[11.2 Laser Driven Flyer Plate](#)

[11.3 Direct Laser Ignition](#)

[References](#)

[Chapter 12: Conclusions and Future Prospect](#)

[12.1 Introduction](#)

[12.2 Theoretical Considerations](#)

[12.3 Lasers](#)

[12.4 Optical and Thermal Properties of Energetic Materials](#)

[12.5 State of the Art: Laser Ignition](#)

[12.6 Future Prospect](#)

[References](#)

[Index](#)

[End User License Agreement](#)

List of Tables

[Chapter 1](#)

[Table 1.1](#)

[Chapter 2](#)

[Table 2.1](#)

[Chapter 3](#)

[Table 3.1](#)

[Table 3.2](#)

[Table 3.3](#)

[Chapter 4](#)

[Table 4.1](#)

[Table 4.2](#)

[Table 4.3](#)

[Table 4.4](#)

[Table 4.5](#)

[Table 4.6](#)

[Chapter 5](#)

[Table 5.1](#)

[Table 5.2](#)

[Table 5.3](#)

[Table 5.4](#)

[Table 5.5](#)

[Chapter 6](#)

[Table 6.1](#)

[Table 6.2](#)

[Table 6.3](#)

[Table 6.4](#)

[Table 6.5](#)

[Table 6.6](#)

[Chapter 7](#)

[Table 7.1](#)

[Table 7.2](#)

[Table 7.3](#)

[Table 7.4](#)

[Chapter 9](#)

[Table 9.1](#)

[Table 9.2](#)

[Chapter 10](#)

[Table 10.1](#)

[Chapter 11](#)

[Table 11.1](#)

List of Illustrations

[Chapter 1](#)

[Figure 1.1 Small-scale basic ballista. Reproduced with permission from Cranfield University © 2014.](#)

[Figure 1.2 Crecy bombard 1346. Reproduced with permission from Cranfield University © 2014.](#)

[Figure 1.3 Showing a field gun in the foreground and a naval gun in the background. Reproduced with permission from The Mary Rose Trust. © The Mary Rose Trust, 2014.](#)

Figure 1.4 Showing active region of a breech-loaded cannon as used on the *Mary Rose*. Reproduced with permission from The Mary Rose Trust. © The Mary Rose Trust, 2014.

Figure 1.5 Leonardo Da Vinci's sketches for multi-barrelled cannon systems.

Figure 1.6 Leonardo Da Vinci-designed siege mortars.

Figure 1.7 Showing ignition systems in musketry. Top left: original flintlock. Top right: wheel lock. Bottom: first percussion cap system. Reproduced with permission from Cranfield University © 2014.

Figure 1.8 Shrapnel's exploding cannon shell \approx 1780. Reproduced with permission from Cranfield University © 2014.

Figure 1.9 Congreve's exploding warhead rocket.

Chapter 2

Figure 2.1 First experiments with laser initiation of secondary explosives. Reprinted with permission from [84]. Copyright 1971, AIP Publishing LLC.

Figure 2.2 Schematic of alternative methods of laser initiation of energetic materials.

Chapter 3

Figure 3.1 Electromagnetic spectrum extending from radio wave up to gamma radiation. Reproduced from <http://upload.wikimedia.org/wikipedia/commons/8/8a/Electromagnetic-Spectrum.png>.

Figure 3.2 Theoretical spectra of radiation emitted from an ideal 'black body' at different temperatures (based on Plank Radiation Law).

[Figure 3.3 Comparison between: \(a\) broad band spectrum of solar radiation and, \(b\) narrow band spectrum of a laser beam \(concept of laser line and line width\).](#)

[Figure 3.4 Example of temporal history of a solid-state pulsed \(Q-switched\) laser.](#)

[Figure 3.5 Intensity profiles of a Gaussian beam \(a\) and a multimode laser beam \(b\). Reproduced with permission from Rüdiger Paschotta. © 2013.](#)

[Figure 3.6 Schematic for the visualization of the cross-sectional structure of electronic orbitals in a carbon atom. Reproduced from Atom Structure by Jerry Coffey on February 22, 2010, <http://www.universetoday.com/56747/atom-structure/>.](#)

[Figure 3.7 Schematic of atomic transitions illustrating stimulated emission process. Reproduced from \[http://en.wikipedia.org/wiki/File:Stimulated_Emission.svg\]\(http://en.wikipedia.org/wiki/File:Stimulated_Emission.svg\).](#)

[Figure 3.8 An artist's sketch illustrating the components of a practicable laser. Principal components: 1. Gain medium; 2. Laser pumping energy; 3. High reflector; 4. Output couple \(low reflector\); 5. Laser beam. Reproduced from <http://en.wikipedia.org/wiki/Laser>.](#)

[Figure 3.9 Wavelength range of laser outputs from some molecular/atomic species. Reproduced from <http://holoinfo.no-ip.biz/wiki/index.php/Laser>.](#)

[Figure 3.10 Schematic of the structure and operational principle of a diode laser.](#)

[Figure 3.11 Diffraction-limited spot size at the focus of a lens for a parallel laser beam.](#)

[Figure 3.12 Schematic of a typical fibre optics laser beam coupling system.](#)

[Chapter 4](#)

[Figure 4.1 Reaction scheme for NC production.](#)

[Figure 4.2 Reaction scheme showing the main products from the nitration of toluene with nitric acid.](#)

[Figure 4.3 Isomers of trinitrotoluene.](#)

[Figure 4.4 Structure of picric acid and dinitroresorcinol.](#)

[Figure 4.5 Production of HMX and RDX from hexamine.](#)

[Chapter 5](#)

[Figure 5.1 Structure of TATB.](#)

[Figure 5.2 FOX 7,1,1'dinitro2,2'diaminoethene.](#)

[Figure 5.3 Hydroxyterminated polybutadiene \(HTPB\).](#)

[Figure 5.4 Reduced sensitivity explosives.](#)

[Figure 5.5 Some suggested structures for pure polynitrogen molecules.](#)

[Figure 5.6 Variations of five-membered rings.](#)

[Figure 5.7 Variations on nitro-1,2-pyrroles, showing amine and nitramine variants.](#)

[Figure 5.8 Compounds based on the tetracarbazole ring.](#)

[Figure 5.9 Compounds with multiple tetracarbazole rings linked together either by nitrogen species or carbon-containing moieties.](#)

[Figure 5.10 Six-membered ring systems.](#)

[Figure 5.11 Six-membered ring systems with three nitrogen atoms.](#)

[Figure 5.12 Tetrazines.](#)

[Chapter 6](#)

[Figure 6.1 Simple schematic of the burning process.](#)

[Figure 6.2 Detailed cross section through burning particle.](#)

[Figure 6.3 Schematic temperature profile for a burning spherical particle of explosive.](#)

[Figure 6.4 Effect of increased pressure on the linear burn rate of a material with \$\alpha < 1\$.](#)

[Figure 6.5 Propellant charges are made of a large number of small particles or using large, porous particles characterized by the multitubular arrangement shown here.](#)

[Figure 6.6 Linear burn rate as a function of pressure for \$\alpha > 1.0\$.](#)

[Figure 6.7 Fragments produced from deflagrating of a 450 Kg bomb.](#)

[Figure 6.8 Burn rate with pressure profile for some 'platonised' propellants.](#)

[Figure 6.9 Shockwave propagation through a stick of explosive and the corresponding pressure profile along the stick.](#)

[Figure 6.10 Burning rate of HMX pressed powders as a function of pressure for various particle size materials \[1\].](#)

[Figure 6.11 Variation of predetonation column length as a function of permeability/particle size and TMD for HMX and PETN powders samples.](#)

Figure 6.12 Detonation transition regions for RDX (l) and HMX (r) showing variations with density and particle size.

Figure 6.13 Schematic pressure profile of a shock to detonation from a donor charge passing through a barrier, which is typically a metal casing.

Figure 6.14 Indicating the critical diameter and effect of diameter on the velocity of detonation for an unconfined charge.

Figure 6.15 Effect of confinement strength on velocity of detonation, D , as a function of charge diameter y (plotted as $1/D$ against $1/y$).

Figure 6.16 Typical component propellant and warhead systems in an artillery shell.

Figure 6.17 Energy released from a detonation.

Figure 6.18 Possible decomposition schemes for TNT.

Figure 6.19 Thermodynamic Cycle for formation and decomposition of RDX.

Figure 6.20 Heat of explosion as a function of oxygen balance.

The Dautriche Method for VoD determination.

Schematic of the basic rotating mirror streak camera.

Idealized photographic trace from rotating mirror streak camera.

Continuous wire method for VoD.

Schematic arrangement for event system of VoD measurement.

Chapter 7

Figure 7.1 Typical energy profile of an energetic material decomposition reaction.

Figure 7.2 The Maxwell-Boltzmann distribution of molecular energy levels at two arbitrary temperatures. E is the mean energy and E_a the activation energy for the decomposition reaction.

Figure 7.3 Effect of activation energy value on the rate of reaction.

Figure 7.4 Rate of charge decomposition as a function of charge temperature.

Figure 7.5 Plots of heat generated and heat lost by a system as a function of temperature.

Figure 7.6 Rate of decomposition vs temperature, for different explosives.

Figure 7.7 (a) TNT decomposition scheme. (b) Some of the detected products.

Figure 7.8 Scheme for the decomposition of EGDN (ethyleneglycol dinitrate).

Figure 7.9 Suggested scheme for the decomposition of RDX.

Figure 7.10 Products of the photodecomposition of DMNA.

Figure 7.11 RDX, showing possible formation of the transient five-membered ring and elimination of the HONO species by bond schism across the dotted lines in the figure.

Figure 7.12 Two tetra-nitro isomers produced by photo induced loss of two NO_2 radicals from CL20.

Figure 7.13 Energy curve for the decomposition of an explosive.

[Figure 7.14 Percussion cap for small arms cartridge.](#)

[Figure 7.15 Stab igniter for shell fuze detailing alternative filling compositions.](#)

[Figure 7.16 Arrangement for conducting cap igniter.](#)

[Figure 7.17 Illustration of an artillery round containing two separate trains - one of each kind.](#)

[Figure 7.18 Schematic explosive trains in HE shell ammunition.](#)

[Figure 7.19 Electric demolition detonator.](#)

[Figure 7.20 Stab detonator as in bomb fuze.](#)

[Figure 7.21 Flash-receptive detonator as in 105 mm HE shell fuze.](#)

[Figure 7.22 Direct impact fuze as in 84 mm HEAT projectile.](#)

[Figure 7.23 Schematic of slapper detonator.](#)

[Figure 7.24 Schematic of early laser ignition experiments adapted from \[30\].](#)

[Figure 7.25 DSC scans for various energetic materials showing phase transitions and decomposition.](#)

[Figure 7.26 DSC of ammonium nitrate, showing phase transitions and decomposition.](#)

[Figure 7.27 Schematic of exploding bridgewire detonator.](#)

[Chapter 9](#)

[Figure 9.1 Absorption spectra of some typical pyrotechnic materials.](#)

[Figure 9.2 Absorption spectra of some propellant samples.](#)

Figure 9.3 Typical absorption spectrum of the explosive material, HNS.

Figure 9.4 Chemical structures of some potential LOVA energetic fillers.

Figure 9.5 Absorption spectra of two different experimental LOVA propellants.

Chapter 10

Figure 10.1 Schematic representation of the temporal history of laser ignition (ignition map).

Chapter 11

Figure 11.1 An artist's sketch of a guided weapon system (GWS) operated by different laser beams taken from a single powerful laser.

Figure 11.2 Schematic of a laser-driven flyer plate technique for the initiation of detonation in high explosives.

Figure 11.3 (a) Schematic of a typical experiment layout for laser ignition test in open air using an Ar-ion laser. (b) Schematic of a typical experiment layout for laser ignition test in the open air using a diode laser. Reproduced from [16]. Copyright © 2005 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.4 Molecular structures of some common high explosives.

Figure 11.5 Typical optical absorption spectra of some common explosives. Reproduced from [18]. Copyright © 2008, Royal Society of Chemistry.

Figure 11.6 Example of temporal history of a laser-induced ignition event. Reproduced from [10]. Copyright © 2001 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.7 Typical oscilloscope trace of ignition event in an explosive material.

Figure 11.8 Typical absorption spectra of some in-service propellants. Reproduced from [10]. Copyright © 2001 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.9 Temporal history of a typical laser ignition event for CDB propellants. Reproduced from [17]. Copyright © 2001 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.10 Absorption spectra of some pyrotechnics with different compositions.

Figure 11.11 Oscilloscope trace of an ignition event in gunpowder following Ar-ion laser beam irradiation (beam intensity at target $\approx 75 \text{ W cm}^{-2}$; laser wavelength @500 nm). Reproduced from [16]. Copyright © 2005 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.12 Example of an ignition map for a pyrotechnic using Ar-ion laser (@500 nm). Reproduced from [16]. Copyright © 2005 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.13 Engineering sketch of a confinement chamber for laser ignition tests. Reproduced from [17]. Copyright © 2008 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Figure 11.14 Example of temporal history of low order detonation event in NiHN. Time to detonation = 33.3 ms, laser energy density = 7.21 J cm^{-2} . Reproduced from Ref [19].

About the Authors



Dr S Rafi Ahmad

Dr Ahmad founded the Centre of Applied Laser Spectroscopy within Cranfield University (CU) in 1988 and led it until he retired in 2012. He received the degree of D.Phil. from the University of Oxford (UK) in 1972 on his thesis on 'Laser Interaction with Solid Materials'. During his career as a scientist within the Ministry of Defence (UK), and later as an academic at CU, the scope of his research areas expanded to include, among many diverse topics, laser ignition of energetic materials and laser-induced processing of natural and synthetic polymers for biomedical applications. His research was funded by many national and international bodies and he was the principal investigator and the coordinator of a number of EU funded projects involving many partners from EU countries in research topics including Jute modification (INCO-DC) and plastic identification (BE-7148). He also served as the UK representative in the management committee of the EU's EULASENET network and one of the co-coordinators of the COST-G7 action on artwork preservation using lasers. Dr Ahmad retired from Cranfield University in 2012. He has supervised 11 PhD students and published 62 peer reviewed papers and other books.



Dr Michael Cartwright

After graduating in chemistry from London in 1963, Michael Cartwright gained industrial experience in the nuclear industry at Windscale and pharmaceutical research in London, before moving to Bath University as a researcher in nuclear chemistry. He was awarded a D.Phil by London University in 1974 for a thesis on 'Radiation Damage in Solids', based on research work performed at Bath University. He then proceeded to do research in inorganic thermo-chemistry and organo-metallic coordination complex chemistry. His interest expanded towards structural chemistry and X-ray diffraction which resulted in later years in his inauguration of the University's first single crystal four circle structure determination facility.

He moved to Cranfield University, at RMCS Shrivenham, in 1986, to lecture and perform research in energetic materials. His major interest was the relationship between molecular structure and explosive sensitivity, which developed into a series of lectures for the M.Sc in Explosives Ordnance Engineering. He was co-founder of the M.Sc. Forensic Engineering and Science course and he helped to develop the university's interests in the environmental impact of explosives, particularly in waste waters from manufacturing plants and land contamination at munitions disposal sites. He helped to design the inter-

site master's courses on environmental diagnostics and waste water chemistry. Energetic materials research was funded by the MOD, government agencies, research organisation and private companies. He represented CU on the SCC of the MOD, devising test methods for assessment of accidental initiation risks for energetic materials. He also represented CU on several NATO organisations, examining various aspects of energetic material science. He retired from Cranfield in 2009.

Preface

The practical laser was invented by T. H. Maiman at the Hughes Research Laboratories in the USA, way back in 1960. It was then hailed as 'the tool looking for applications'. In no time, the tool found applications in almost all fields of science and technology. The headline defence application was in a 'Star Wars' anti-missile system but, not surprisingly, within a couple of years, research and development on its applications in the defence industry, particularly for high explosives ignition/initiation, got under way. Due to the 'Cold War' prevailing at the time, most of this research was shrouded in secrecy. However, for a variety of reasons, there has been a long pause in tangible developments in this field until recently. Current emphasis on the safety of energetic materials during manufacture, storage, use and transportation, has prompted a spate of research activities throughout the industrial world on the synthesis and ignition initiation of high-performance munitions. These must have whole-life cost-effectiveness, through-life safety and end-of-life environmentally friendly disposal options. These aspects are the objectives of research and development in this field, and the book aims to elucidate the background and the current state of the art in the field of laser initiation.

The book starts with a brief chronological resume of the invention, development and the use of materials generally termed 'explosives'. This is intended as a purely historical background introduction and is compiled from various sources. An extensive review of the research and development in the application of lasers for ignition/initiation in energetic materials, identifying some of the critical parameters involved, is provided in Chapter

2. This includes a number of references, in addition to a bibliography of recent relevant publications.

Since the book topic encompasses two very different fields of science and technology, these are, for completeness and convenience of the readers, elaborated in Chapters 3 and 4. Chapter 3 provides the basic science behind the technologies, manufacture and general properties of lasers, while Chapter 4 provides a background to the general properties and synthesis of energetic materials. This includes the essential components, both as mixtures of fuels and oxidiser and single energetic molecules, with a chemical classification of these latter materials. The contents are considered to be adequate background for researchers in this field. There are also references and bibliography for the inquisitive reader. Note that further information on these topics is readily available in a number of open literature sources.

Chapter 5 examines the limitations of the current materials and methods of improving safety, for example, with plastic bonded explosives, PBXs and so on. Consideration is also given to the synthesis of new explosives, an active field of research and development. Some of these newer materials are less environmentally toxic. It was therefore considered prudent to include a chapter reviewing these aspects and, in particular, high nitrogen materials, since some of these materials may find future applications in laser ignition.

Fundamental processes associated with the decomposition of energetic materials, ranging from simple burning through deflagration to detonation, are discussed in Chapter 6, along with the effects of explosives in terms of shock pressure and explosive power. Additional methods of improving explosive power are discussed. A brief appendix details some of the methods used for measuring velocity of the shock wave. Chapter 7 examines the energetic changes

associated with the initiation process and the currently used techniques for the initiation of energetic materials, with only brief reference to the use of optical or laser systems. Classification of explosives by ease of initiation and the use of explosives trains to minimise hazards are considered, along with the basic properties of current initiatory primers. For both general safety and for safe ignition using lasers, a synopsis of the development of alternative primary explosives is presented in Chapter 8. Some of the materials discussed show particular sensitivity to laser radiation and have high explosive performance, sometimes in excess of existing high explosives.

The theoretical basis of laser interaction with energetic materials involves both optical and thermal properties of materials and both these aspects are covered in Chapters 9 and 10. Chapter 11 provides a synopsis of practical research conducted in this field, mainly citing examples of work carried out at the authors' laboratories. Finally, a general conclusion of the work conducted so far in this field, and the future prospects and direction of research, is included in Chapter 12.

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1

Historical Background

1.1 Introduction

Historically, mankind has tried to dominate both fellow human beings and other animals for as long as humans have been around. Some of this domination was achieved by killing other species. This had two aspects; survival and providing food.

Survival was dictated by the fact that many animals regarded humans as excellent sources of food and were quite capable of killing humans. Humans could have two approaches; avoid areas known to contain threatening species or produce devices - weapons - which would enable humans to kill the threatening animals. Humans then developed a taste for the flesh of some of the animals they had killed, thus increasing the sources of food available. As the human population increased, conflict between humans for food and territory increased, and so humans started to fight amongst themselves. By using weapons, humans could overcome physical disadvantages, and the optimum situation was to be able to kill your opponent before they could kill you.

The sword and lance effectively extended the human arm and kept your opponent at bay but, as lances became longer and longer, they became more unwieldy. A remote killing weapon was required. Simple javelins, which could be thrown at the opposition, extended the distance between opponents but required considerable physical stature and skill to achieve the correct flight trajectory for the javelin. Therefore, in order to overcome human physical

limitations, mechanical advantage devices were used. The earliest weapons for remote killing were simple slings. These could carry a stone and were capable of accelerating it to high velocity by spinning the sling in a circle. When one of the supporting thongs was released, the stone would travel in an almost straight line from the point of release. Impact of the stone with an animal or human was capable of killing or injuring the animal.

With the development of wood manufacturing skills, bows and arrows became individual weapons or, when grouped together became a lethal hail of arrows which did not depend on the individual accuracy of the archer. The longbow was the ultimate in these weapons. Improved performance came when mankind developed stored energy devices, such as the ballista and crossbows, both of which stored mechanical energy in wooden elements but required winding up before loading the stone or arrow projectile. These overcame the limitations of physical stature required to effectively use the longbow. The ballista, [Figure 1.1](#), was also used to fire barrels of burning oil at the enemy when they had formed shield walls against arrows. The oil container burst on impact and was one of the first deployments of pyrotechnics weapons.