Chapter 9

Nanotechnology and the Law of Armed Conflict

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Abstract Nanotechnology is a rapidly evolving field of science cutting across many disciplines including engineering, quantum physics, optics, chemistry and biology, and typically involves manipulation of matter on the atomic and molecular level in the size range of 1–100 nm ($1 \text{ nm} = 10^{-9} \text{ m}$) in one or more external dimensions. It enables, for example, the increased and tailored rate of energy release, manipulation of optical properties, increased electrical conductivity, and improved hardness and strength with reduced weight, which can find useful applications for advanced military equipment and weaponry. The introduction of nanotechnology into weaponry is also expected to influence the application and interpretation of the law of armed conflict, raising the question as to whether the existing rules are sufficiently clear and adequate in light of the technology's specific characteristics, as well as with regard to the foreseeable humanitarian impact it may have. This chapter revisits the rationale underlying the law of armed conflict and examines to what extent the problems arising from the use of nanotechnology-enhanced or enabled weapons could adequately be addressed within the current legal framework governing weaponry. To that end, this chapter focuses on the three enhanced capabilities that nanotechnology introduces to weaponry: (1) penetration; (2) accuracy and manipulation in the delivery of focused force application; and (3) camouflaging.

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9.1 Introduction

Nanotechnology is a rapidly evolving field of science cutting across many disciplines including engineering, quantum physics, optics, chemistry and biology, and typically involves manipulation of matter on the atomic and molecular level in the size range of 1–100 nm (1 nm = 10^{-9} m) in one or more external dimensions. It is widely considered a next-generation transformational technology with profound implications for all aspects of modern society including warfare. In fact, the use of nanotechnology enables, for example, the increased and tailored rate of energy release, manipulation of optical properties, increased electrical conductivity, and improved hardness and strength with reduced weight, which can find useful applications for advanced military equipment and weaponry. The introduction of nanotechnology into weaponry is also expected to influence the application and interpretation of the law of armed conflict, raising the question as to whether the existing rules are sufficiently clear and adequate in light of the technology's specific characteristics, as well as with regard to the foreseeable humanitarian impact it may have.

This chapter revisits the rationale underlying the law of armed conflict and examines the extent to which the legal challenges arising from the use of nanotechnology-enhanced or enabled weapons could adequately be addressed within the current legal framework governing weaponry. To that end, this chapter starts by explaining the relevance of nanotechnology to weapons capabilities and its general impact on the law of armed conflict. A legal assessment then follows with the focus on the following three enhanced capabilities that nanotechnology introduces to weaponry: (1) penetration; (2) accuracy and manipulation in the delivery of focused force application; and (3) camouflaging.

9.2 Military Applications of Nanotechnology

Nanotechnology is widely considered a transformational technology with profound implications for all aspects of modern society. There is no generally agreed definition of nanotechnology, but it typically involves manipulation of matter on the atomic and molecular level in the size range of 1–100 nm (1 nm = 10^{-9} m) in one or more external dimensions. This technology in and of itself does not present any harm to human bodies that can be exploited for military purposes; it is its enabling applications particularly through the development and use of engineered nanomaterials and nanoparticles that are relevant to enhancing weapons capabilities.

Any existing matter can be manipulated to produce engineered nanomaterials and nanoparticles, but they are distinguished from anthropogenic ultrafine particles (for example, aerosols that originate from combustion processes or through friction on road surfaces, brakes and tyres) insofar as engineered nanomaterials and nanoparticles are manufactured intentionally with defined properties and mostly with a narrow size distribution.¹ A wide variety of substances have been tested for nano-scale engineering, but predominantly nanotechnological applications are currently sought from metal particles in order to take advantage of various unique characteristics that metal engineered nanomaterials and nanoparticles possess such as the large surface area, increased electrical conductivity, and improved hardness with reduced weight.² Many of those unique characteristics of engineered nanomaterials and nanoparticles have great potential for transforming military capabilities and the way in which warfare is fought in the future.

Scientifically, there appears to be little in the way of exploring all the imaginary weapons capabilities with the use of nanotechnology, including remote control of animals for hostile purposes, autonomous micro-robots and micro-fusion nuclear warheads.³ In reality, however, nanotechnological development will not necessarily be prone to producing those unconventional weapons, or at least will not directly lead thereto. This is because current weapons development programmes are embedded in the existing weapons manufacturing infrastructures and integrated weapons systems based on conventional technologies, which do not easily allow major restructures or an overhaul of existing military infrastructures to take advantage of nanotechnological innovation. A viable, cost-effective option is the replacement of one component with a nanotechnology-enabled or enhanced product that interfaces with other components in a standard way.⁴ Another factor is the fact that the weapons development programmes are by and large driven by the 'needs' of troops as perceived from their past and present experiences (for

¹ Fiedeler and Fries 2012, pp. 1–2.

² Ibrügger 2005; Wang and Dortmans 2004.

³ Altmann 2006, pp. 93–101.

⁴ Benkoski et al. 2012

example, greater situational awareness and improvised explosive device (IED) detectors),⁵ rather than by the 'possibilities' that nanotechnology may present.

In light of those practical constraints, military applications of nanotechnology are primarily found in the enhancement of existing military capabilities: for example, soldier survivability with the development of lighter, stronger and heat-resistant armour and clothing; troop mobility with miniaturisation of communication devices and more efficient energy storage and generation; manoeuvrability with greater precision targeting sensors; enhanced optical camouflaging; and focused force application.⁶ Many of those applications of nanotechnology result in nothing more than an improvement to existing military equipment and do not present any challenge to the way in which modern warfare is engaged or to the application of the law of armed conflict. However, there are some areas where an introduction of nanotechnology will present legal or ethical challenges that require examination in light of the existing principles and rules of the law of armed conflict.

9.3 Enhanced Penetration Capabilities

Applications of nanotechnology to energetic materials and ingredients have the potential to increase performance in ignition, propulsion and explosion because nano-energetics can store higher amounts of energy than conventional energetic materials.⁷ Metal powders, such as aluminium, have commonly been incorporated as additives in composite high explosives, but enhanced detonation parameters are recorded only for mixtures of aluminium with strong oxidizers at a micron size.⁸ Nano-energetic composites such as Metastable Intermolecular Composites (MICs)—mixtures of nano-scale metal powders that allow for tailoring the rate of energy release by varying the particle size in a nano-scale—are considered particularly useful ingredients in enhancing blast weapons such as thermobaric explosives.⁹

Since its use in the 1960s, enhanced blast weapons such as fuel air explosives and thermobaric explosives have been constantly evolving—these weapons are designed to kill or injure by primary blast effect and incendiary or thermal effects as a secondary source of injury and damage.¹⁰ Upon detonation, these explosives release blast waves causing overpressure injuries to the lungs and other internal organs and also release a plasma cloud that reaches temperatures of 2,500–3,000 °C, increasing

the burn threat from flame contact and thermal radiation.¹¹ Enhanced blast weapons are particularly found to be useful tactical weapons capable of destroying targets inside hardened, deeply buried structures and buildings.¹² The use of nano-energetics—for example, thermobaric explosives enhanced by aluminium nano-particles—is considered to accelerate the rate of chemical reaction (energy release) and enhance the lethal range, although no scientific report has been released to the public as to the precise magnitude of damage.

The use of such nanotechnology-enhanced blast weapons in the battlefield as tactical weapons raises an issue as to whether this is prohibited under Article 35(2) of *Additional Protocol I* as the employment of weapons of a nature that causes superfluous injury or unnecessary suffering,¹³ which is now widely considered to be a general principle of customary international law.¹⁴ As the present author examined elsewhere, even though it is arguable that an expanded reading of 'unnecessary suffering' may well require the blast and incendiary effects to the health of surviving victims and the environment to be taken into account, the ambiguity regarding the application of the principle makes it difficult to prove that the suffering is superfluous or unnecessary.¹⁵ Also, these weapons will not be considered to be prohibited as incendiary weapons under *CCW Protocol III*,¹⁶ or as asphyxiating or poisonous gases under Article 23(a) of the 1907 *Hague Regulations* and the 1925 *Geneva Protocol*,¹⁷ given that the incendiary or thermal effects are only designed to be a secondary, not primary, cause of injury.¹⁸

However, both the design intent and the actual effects of the enhanced blast weapons draw striking similarities with those of nuclear weapons,¹⁹ leaving, of course, nuclear radiation injury aside. In fact, the United States (US) Department of Defense and Department of Energy led the study into Robust Nuclear Earth

¹¹ Andrew 2003, pp. 9–10; Bean 2004, p. 49.

¹² Fry 2006, pp. 503–504.

¹³ *Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts (Protocol I)*, 12 December 1977, 1125 UNTS 3 (entered into force 7 December 1979) ('*Additional Protocol I*').

¹⁴ Henckaerts and Doswald-Beck 2005, rule 70, p. 237.

¹⁵ Nasu and Faunce 2010, pp. 34–43.

¹⁶ *Protocol on Prohibitions or Restrictions on the Use of Incendiary Weapons (Protocol III) to the Convention on Prohibition or Restrictions on the Use of Certain Conventional Weapons Which May be Deemed to be Excessively Injurious or to Have Indiscriminate Effects*, 10 October 1980, 1342 UNTS 171 (entered into force 2 December 1983) ('*CCW Protocol III*').

¹⁷ *Regulations Concerning the Laws and Customs of War on Land, Annex to the Hague Convention (IV) Respective the Laws and Customs of War on Land*, 18 October 1907, 205 CTS 277 (entered into force 26 January 1910) ('*Hague Regulations*'); *Protocol for the Prohibition of the Use of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare*, 17 June 1925, 94 LNTS 65 (entered into force 8 February 1928) ('*Geneva Protocol*').

¹⁸ Boothby 2009, p. 201; cf. Fry 2006, pp. 501–506.

¹⁹ For a detailed description of the biological effects of nuclear weapons, see, Glasstone and Dolan 1977, Chap. 12.

⁵ Cf Sloan 2002, p. 15.

⁶ Nasu 2012; Blake and Imburgia 2010, p. 180.

⁷ Miziolek 2002, p. 43.

⁸ Kanel et al. 2009, pp. 15–16.

⁹ Miziolek 2002, p. 44.

¹⁰ Bean 2004, p. 49.

Penetrator (RNEP) that commenced in 2002, basically exploring the possibility of developing a lower-yield nuclear weapon capable of penetrating or destroying hardened and deeply buried facilities without causing excessive collateral damage.²⁰ Yet, when it detonates underground, as is intended, there was serious doubt as to whether it could penetrate deep enough to contain the nuclear explosion and the radiation it would consequently produce.²¹ The use of nano-energetics may provide a promising alternative to achieve the same objective without using nuclear materials.

Free from nuclear radiation, enhanced blast weapons may well be regarded as appealing for practical use in destroying targets inside hardened and deeply buried structures without causing mass civilian casualty from exposure to radiation, enabling them to be used as tactical weapons, rather than strategic weapons like nuclear warheads. Yet, it does not necessarily free them from consideration of collateral damage as a result of the primary blast and secondary incendiary effects of explosion. For example, in the case of targeting underground storage sites that contain biological and chemical agents, those hazardous materials are unlikely to be incinerated by an earth penetrating weapon, but instead may be disseminated to the ground surface and into the atmosphere.²² More fundamentally, the use of such nanotechnology-enhanced blast weapons, due to the wide range of lethal and damaging effects, could well in and of itself be considered inherently incapable of discriminating civilians from legitimate military objectives as required by the principle of discrimination.²³

In this respect, the International Court of Justice (ICJ)'s advisory opinion in *Nuclear Weapons* should be recalled. Relevant to the current discussion is the argument made by the US in its written submission to the Court, which emphasised a wide variety of circumstances nuclear weapons might be used with very different results in terms of likely civilian casualties, pointing specifically to 'the use of a low yield nuclear weapon against warships on the High Seas or troops in sparsely populated areas'.²⁴ Whist re-affirming the applicability of humanitarian law to nuclear weapons,²⁵ the Court considered that:

[I]t does not have sufficient elements to enable it to conclude with certainty that the use of nuclear weapons would necessarily be at variance with the principles and rules of law applicable in armed conflict in any circumstance.²⁶

²⁰ Medalia 2004, pp. 44–47.

²¹ Sidel et al. 2003, p. 2; Nelson 2002.

²² Sidel et al. 2003, p. 3.

²³ *Additional Protocol I*, Articles 48 and 51(4); Henckaerts and Doswald-Beck 2005, r. 1.

²⁴ As cited by the Court in *Legality of the Threat or Use of Nuclear Weapons (Advisory Opinion)*, ICJ Reports 1996, 226 ('*Nuclear Weapons*'), p. 261, para 91.

²⁵ *Nuclear Weapons*, pp. 259–260, paras 85–86.

²⁶ *Nuclear Weapons*, p. 263, para 95; cf Dissenting Opinion of Judge Higgins, p. 583, paras 25–26; Dissenting Opinion of Judge Weeramantry, p. 477, part III; Dissenting Opinion of Judge Koroma, p. 556; Dissenting Opinion of Judge Shahabuddeen, p. 402.

This is despite the observation by the Court that 'none of the States advocating the legality of the use of nuclear weapons under certain circumstances... has indicated what, supposing such limited use were feasible, would be the precise circumstances justifying such use'.²⁷ To the extent that the same argument applies to the use of nanotechnology-enhanced blast weapons, no matter how wide range and extensive its lethal and damaging effects might be, it would not be considered inherently indiscriminate.²⁸ The practical consequence is the presumed legality of those nanotechnology-enhanced blast weapons, even though these are likely to be used as tactical weapons, unlike nuclear weapons which are considered to be strategic weapons, and therefore the 'policy of deterrence' to which the Court attached some significance in its reasoning does not restrain the use of such weapons in battlefields.

9.4 Enhanced Accuracy and Manipulation of Weapons Projection

Nanotechnology is also expected to contribute to dramatically improving energy density in storage and conversion rate,²⁹ reducing the size of integrated systems at a nano-scale,³⁰ and enhancing the sensitivity and accuracy of sensing.³¹ These technological advancements will enable mechanical precision and manipulation of force projection with a range of munitions such as self-guiding bullets, projectiles and missiles.

In 2005, the US Defense Advanced Research Projects Agency (DARPA) initiated the 'nano air vehicles' program to develop extremely small, ultra lightweight airborne vehicles (less than 15 cm and less than 20 g) capable of performing indoor and outdoor military missions.³² The development of nano air vehicles requires advancements in aerodynamic design for low Reynolds number airfoils, lightweight and efficient propulsion, energy storage systems, autonomous guidance and navigation, sensors and communication sub-systems and manufacturing techniques to achieve the high level of system integration.³³ It can be considered as a class of unmanned aerial vehicles (UAVs), but the development of nanotechnology will enable further miniaturisation with its application for high density energy storage, enhanced efficiency in energy conversion to propulsion as well as operation of all the sub-systems, and integrating navigation, guidance and control

²⁷ *Nuclear Weapons*, p. 262, para 94.

²⁸ McCormack 1997, pp. 85–88.

²⁹ See, for example, Candelaria et al. 2012; Aricò et al. 2005.

³⁰ See, for example, Last et al. 1999.

³¹ See, for example, Levitsky 2010; Kosal 2009, pp. 43–52.

³² DARPA Defense Science Office 2013.

³³ Davis 2007, pp. 6–7.

onto a single chip to meet the restrictive size, weight and power requirements for nano air vehicles. Ultimately, the level of sophistication may reach the point where nano air vehicles manoeuvre their way in almost exactly the same way as natural insects do.

Mechanical precision and the ability to manipulate projection of munitions in targeting operations with the use of those nanotechnology-enabled weapons will not only facilitate a greater level of compliance with the principle of discrimination, but also expand lawfully targetable options by reducing the scope of collateral damage that may be expected to be excessive in relation to the direct military advantage anticipated.³⁴ In addition, the current debate as to whether the military with advanced technology should be always required to use precision-guided munitions to avoid or minimise civilian collateral damage,³⁵ will continue to be relevant to the use of nanotechnology-enabled precision weapons.

It is inconceivable that these nanotechnology-enabled precision-guided munitions will be considered contrary to the principle prohibiting superfluous injury or unnecessary suffering, as these are not intended, nor are expected, to inflict excessive harm on the victim. However, legal concerns for cruel effects of weapons are not limited to superfluous injury or unnecessary suffering. Indeed, the 1868 *St Petersburg Declaration*, which for the first time in the modern history enunciated the principle prohibiting superfluous injury or unnecessary suffering, stated in the preamble that 'the employment of arms which uselessly aggravate the sufferings of disabled man, or render their death inevitable... would, therefore, be contrary to the laws of humanity' (emphasis added).³⁶ Whilst the first principle—which prohibits superfluous injury or unnecessary suffering—led to the 1899 *Hague Declaration III* prohibiting the use of expanding bullets and the insertion of Article 23(e) into the 1907 *Hague Regulations*,³⁷ the second—which prohibits rendering death inevitable—was subsequently discussed in the context of the prohibition of asphyxiating gases.

The idea to prohibit the employment of projectiles whose sole purpose is to spread asphyxiating or deleterious gases received an almost unanimous support, but was opened for discussion during the 1899 Hague Conference. Disagreement, although expressed only by the US delegate, stemmed from the basic question as to whether 'it is no more cruel to asphyxiate one's enemies by means of deleterious gases than with water, that is to say, by drowning them, as happens when a

³⁴ *Additional Protocol I*, Articles 51(5)(b) and 57(2)(a)(iii).

³⁵ Rudesill 2007.

³⁶ *St Petersburg Declaration Renouncing the Use, in Time of War, of Explosive Projectiles Under 400 Grammes Weight*, 11 December 1868, 138 CTS 297 (entered into force 11 December 1868) ('*St Petersburg Declaration*'), reproduced in Roberts and Guelff 2000, pp. 54–55.

³⁷ *Hague Declaration (III) concerning Expanding Bullets*, 29 July 1899, 187 CTS 459 (entered into force 4 September 1900) ('*Hague Declaration III*'), reproduced in Roberts and Guelff 2000, pp. 60–61; *Hague Regulations*, Article 23(e).

vessel is sunk by the torpedo of a torpedo-boat'.³⁸ Captain Scheine, the Russian delegate, rejected this comparison by pointing out that:

Many persons may be saved even if they have been wounded or placed out of action, in case a vessel is sunk by a torpedo. Asphyxiating gases, on the contrary, would exterminate the whole crew.

This procedure would therefore be contrary to the humane idea which ought to guide us, namely, that of finding means of putting enemies out of action without putting them out of the world.³⁹

This debate ended with the adoption of this prohibition by almost unanimous support with the exception of the US vote. Drawing on this debate, the late Antonio Cassese concluded that a weapon 'is not in keeping with international law if it *always* results in *killing all* persons who in some way happen to be struck by it' (emphasis original).⁴⁰

The idea appears to have lost track after the adoption of the 1899 *Hague Declaration II* prohibiting the use of asphyxiating gases and the 1925 *Geneva Protocol*, presumably because it was the only method available at that time that would render death inevitable. Therefore it remains unclear whether this principle can be considered to have been established as customary international law, separate to the principle prohibiting superfluous injury or unnecessary suffering or as part thereof, so that it will prohibit the use of those nanotechnology-enabled precision weapons or restrict the way in which it is used—for example, only for temporary incapacitation.⁴¹

The development of modern weaponry with the aid of technological advancement has enabled armed forces to maintain distance between the target and themselves. As a result, even with the increase of fire power and lethality of weapons, the physical distance has by and large rendered this question a moot point (though the legality of nuclear weapons could have been discussed from this perspective). However, the development and use of nanotechnology-enabled precision-guided munitions such as nano air vehicles would arguably bring the current targeting guidance technology to its ultimate form and deprive people of the protection of physical distance from armed attacks. In such a scenario, should the attack by one or more nano air vehicles be compared with the use of asphyxiating gases or more appropriately be analogised to drowning as a result of sinking a vessel by a torpedo? One thing that is certain is that, as nanotechnology enables greater mechanical precision in targeting operations, the possibility of

³⁸ Third meeting of The Hague First Commission, 22 June 1899, reproduced and translated into English in Scott 1920, p. 283.

³⁹ Third meeting of The Hague First Commission, 22 June 1899, reproduced and translated into English in Scott 1920, p. 283.

⁴⁰ Cassese 2008, p. 197.

⁴¹ Cf. Melzer 2008, p. 413 (observing that the prohibition of denial of quarter requires that the operating forces engaging in targeted killing remain receptive to a declaration of surrender should the opportunity arise and suspend any attack against persons who have fallen *hors de combat*).

someone escaping from death from an attack even by a chance will be diminished and that will compel us to consider whether such 'touch of death' technology should be prohibited under the law of armed conflict.

9.5 Enhanced Camouflaging

Stealth technology has already been introduced for military aircrafts to reduce visibility and probability of detection by radar, infrared or other probe beams.⁴² The use of nanotechnology will further enhance this stealth technology and will enable optical camouflage (or adaptive camouflage) with light-absorbing material, making it even harder to detect cloaked weapons and soldiers in the visible and infrared region. For example, L Jay Guo's team demonstrated that the non-reflective and non-scattering characteristics of carbon nanotube coating made an object indistinguishable from the background.⁴³ Applying such cloaking technologies to non-rigid surface such as clothing is challenging. Yet, Andrea Di Falco's team used 'metamaterials', which typically consist of periodic arrays of nano-sized metallic structures, to develop flexible substrates called 'Metaflex' enabling invisibility at the optical range.⁴⁴

When the nanotechnology-enabled invisibility coating is applied to weapons or even to soldiers, it will enable a drastically greater range of covert operations in which their manoeuvre will be undetected. That is even more so when it is combined with other nanotechnology-enabled weapons to enhance manoeuvrability such as 'nano air vehicles' and self-guiding projectiles.

Using optical camouflage across different light spectrums—visible light, night vision spectrum, and thermal/infrared spectrum—to cloak soldiers and their equipment will enable complete invisibility, undetectable by any conventional means of warfare without possessing a technology to detect them. Camouflaging has long been used as a traditional military tactic of deception and is permitted as ruses of warfare under the law of armed conflict.⁴⁵ However, legal questions may be posed regarding the use of nanotechnology-enabled invisibility under certain circumstances.

First of all, it must be considered whether members of an armed force are prohibited from carrying a cloaked weapon or wearing a uniform that makes them invisible during an armed conflict. Article 1 of the 1907 *Hague Regulations* qualifies militia and volunteer corps as combatants, provided they satisfy four conditions, which relevantly include: 'to have a fixed distinctive emblem recognisable at

⁴² Lee 2009, vol. 1, pp. 178–180.

⁴³ Shi et al. 2011.

⁴⁴ Di Falco et al. 2010.

⁴⁵ *Additional Protocol I*, Articles 37(1) and (2); UK Ministry of Defence 2004, p. 64; Green 2000 pp. 146–147, 186–187.

a distance'; and 'to carry arms openly'. Article 4A(2) of *Geneva Convention III* lists the same conditions for according prisoners of war status to members of militias and other volunteer corps.⁴⁶ Although these provisions apply only to irregular armed forces, it does not mean that members of regular armed forces are not required to wear a uniform as a means of distinguishing themselves from the enemy and civilians. Indeed, it was simply considered unnecessary because '[i]t is the duty of each State to take steps so that members of its armed forces can be immediately recognized as such and to see to it that they are easily distinguishable from members of the enemy armed forces or from civilians'.⁴⁷ It is considered a rule of customary international law for members of regular armed forces to wear the uniform of their party to the conflict when directly involved in hostilities.⁴⁸

Wearing an invisibility uniform or using cloaked weapons or vehicles thus raises questions regarding the legal status of cloaked members of regular or irregular armed forces under the law of armed conflict. It should be recalled that one of the purposes of contemporary military uniform is to provide maximum camouflage in the physical environment.⁴⁹ Does optical invisibility go too far, depriving them of the status of combatants for the purpose of the application of the law of armed conflict? Alternatively, are they considered to be 'spies' who, acting clandestinely or on false pretences, obtain or endeavour to obtain information?⁵⁰ Depending upon the answer to these questions, cloaked soldiers may not be accorded protection from prosecution as prisoners of war when captured—although it may be highly unlikely.⁵¹

These questions must also be examined in light of the fundamental principle of distinction and discrimination between combatants and civilians. Wearing a uniform and carrying arms openly have been considered central as a means of distinguishing combatants from civilians. Thus, even though Article 44(3) of *Additional Protocol I* has relaxed the requirements for according prisoners of war status to irregular armed forces fighting against colonial domination, alien occupation or racist regimes,⁵² such forces are still 'obliged to distinguish themselves from the civilian population while they are engaged in an attack or in a military operation preparatory to an attack'. The purpose of this rule, as the Commentary to the Protocol suggests, 'is to protect the civilian population by deterring combatants

⁴⁶ *Geneva Convention Relative to the Treatment of Prisoners of War*, 12 August 1949, 75 UNTS 135 (entered into force 21 October 1950) ('*Geneva Convention III*').

⁴⁷ Pictet 1960, p. 52.

⁴⁸ Ipsen 2008, p. 90.

⁴⁹ Mallison and Mallison 1977, p. 57.

⁵⁰ *Hague Regulations*, Article 29.

⁵¹ See, *Hague Regulations*, Article 30; *Additional Protocol I*, Article 46(1); Baxter 1951, pp. 329–333.

⁵² *Additional Protocol I*, Article 1(4).

from concealing their arms... this failure of even minimal distinction from the civilian population, particularly if repeated, places that population at great risk'.⁵³ Further, even recognising that such irregular forces cannot distinguish themselves owing to the nature of the hostilities, they are still required under the same provision to carry arms openly:

- (a) during each military engagement; and
- (b) during such time as he is *visible* to the adversary while he is engaged in military deployment preceding the launching of an attack in which he is to participate (emphasis added).⁵⁴

While there is a scope for debate as to when a combatant is considered to be engaged in an attack or military deployment, the purpose of protecting civilians by requiring combatants to distinguish themselves from civilians is central to the interpretation and understanding of this provision.⁵⁵ It is thus arguable that the use of enhanced optical camouflage or the use of cloaked weapons and vehicles is considered contrary to the principle of distinction, at least when it directly endangers civilian lives.

Finally, the legality of nanotechnology-enabled cloaking has to be considered in light of the obligation to exercise precautions to protect civilians during attacks and also from the effects of attacks.⁵⁶ It is widely accepted that the obligation to take precautions, to the extent feasible, in planning or deciding upon an attack is a rule of customary international law.⁵⁷ Armed forces are required to take constant care to spare civilian populations in the conduct of military operations, which encompass any movements, manoeuvres and other activities carried out with a view to combat.⁵⁸ Additionally, states are to take necessary, feasible precautions to protect the civilian population under their control against the dangers resulting from military operations. Therefore, the use of nanotechnology-enabled optical camouflaging or cloaking in civilian populated areas in the way that deliberately or knowingly threatens the civilian lives in the vicinity of launching an attack would be considered in breach of the obligation to exercise precautions.

⁵³ Sandoz et al. (eds) 1987, p. 533.

⁵⁴ *Additional Protocol I*, Article 44(3).

⁵⁵ Ferrell 2003, pp. 109–113.

⁵⁶ *Additional Protocol I*, Articles 57 and 58; Quéguiner 2006.

⁵⁷ Henckaerts and Doswald-Beck 2005, r. 15, pp. 51–55.

⁵⁸ Sandoz et al. (eds) 1987, p. 680.

9.6 Conclusion

The introduction of nanotechnology to warfare is already a reality, primarily to enhance military capabilities in several aspects including soldier survivability, troop mobility and manoeuvrability. So far, the practical constraints, rather than legal constraints, have been setting the pace of nanotechnological developments in weaponry. Nevertheless, as this chapter has discussed, certain applications of nanotechnology, for example, to enhance the lethal range of thermobaric explosives, the accuracy and manipulability of weapons projection, and camouflaging, will pose challenges to the application and interpretation of the existing rules of the law of armed conflict. Should we revisit the legal reasoning behind the ICJ's advisory opinion on the legality of nuclear weapons to consider whether nanotechnology-enhanced blast weapons are inherently contrary to the principle of discrimination? Should we revive the debate as to whether an attack that renders death inevitable, for example, by the use of nanotechnology-enabled precision-guided munitions, is prohibited under customary international law? Is the use of nanotechnology-enabled optical camouflaging and cloaking contrary to the principle of distinction or precautions and if it is, what could be the legal consequences of that breach? These are the questions that require a definite answer before any of those nanotechnology-enabled or enhanced weapons are deployed widely in battlefields. An interpretation of the existing rules of the law of armed conflict drawing on the traditional jurisprudence, state practice and authoritative commentaries can only go some way to answer these questions.

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Chapter 11

Nanotechnology and Military Attacks on Photosynthesis

Thomas Faunce

Abstract Advancing scientific knowledge regarding the photosynthetic process at a molecular level has raised the possibility of widespread artificial photosynthetic projects in the future, for example, for large-scale or ‘off-grid’ renewable energy and food production. The value that these projects would have to states and the global community, attracts the possibility that artificial photosynthesis, and the photosynthetic process in general, may become ‘direct’ military targets. This chapter explores the extent to which the existing principles of the law of armed conflict, international environmental law and the *ENMOD Convention* are capable of regulating a direct attack on natural or artificial photosynthesis. In particular, it examines whether the basic principles of international environmental law prohibit direct manipulation of natural or artificial photosynthesis and are applicable during warfare. It then analyses whether natural photosynthesis may be protected from direct military attack under Articles 35(3) and 55 of *Additional Protocol I* or under the *ENMOD Convention*.

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