The Physics of Taekwon-Do

By Matt Gibb BSc (Hons) 2^{nd} dan

General Choi, Hong Hi said that Taekwon-Do is “the scientific use of the body in the method of self defence” and “a martial art that has no equal in either power or technique”.

These are impressive phrases, but what do they mean?

Taekwon-Do practitioners can perform amazing feats of agility and strength: from smashing through roof tiles with the fist to performing complex kicking techniques while jumping over a car; from breaking four pieces of wood in the air with four different techniques to performing a kick to an opponent’s head in a tenth of a second. But these are just everyday acts for many TKD students. The techniques practised in Taekwon-Do are based on the principles of physics, and by applying these principles students of Taekwon-Do can achieve the maximum potential and effectiveness that allow these spectacular displays to be performed.

I started my Taekwon-Do training nearly ten years ago, and I still remember my first lesson. I was being taught dollyo chagi by one of the black belts and had to hold a kick shield so that he could demonstrate the kick. I was quite unprepared for how powerful the kick was. It knocked me backwards a few steps and I got the impression that he had not even put 100% effort into the kick. I was astonished at how a person could generate that kind of power.

Nearly a decade of Taekwon-Do and a degree in physics later I now understand.

In this series of articles I am going to examine in detail the underlying physics that allows students of Taekwon-Do to perform these spectacular techniques. I will give a step-by-step guide with examples and explanations so that someone with no knowledge of physics can understand. It will be intended for everyone, from junior white belts up to senior black belts.

Part 1 – Basic Physics

Brief Introduction to Energy

Before I discuss kinetic energy I will discuss the meaning of the term “energy”.

Energy is the fundamental building block of the universe. It is measured in a unit called joules (J) and can take many forms, such as light, sound, heat, potential, kinetic, even mass (which is a congealed form of energy). Everything around you is a form of energy, including yourself.

Energy can neither be created nor destroyed – it can only be converted from one form into another. This principle is called the conservation of energy. A light bulb, for instance, converts electrical energy into light and heat energy, but the amount of heat and light energy that is emitted is precisely equal to the amount of electrical energy that is input.

A joule is defined as a force of one newton (N) over a distance of one metre (m). In simpler terms: to lift a one kilogram mass from the ground up to a height of 10 cm requires one joule of energy. Other examples that demonstrate energy:

- A 100 watt light bulb uses 100 joules every second;
- A packet of crisps contains approximately 600,000 joules (4.2 joules = 1 calorie);
- In 1993 the world used a total in excess of 300 EJ (exajoules), or 300,000,000,000,000,000,000 joules (*Energy: A Guidebook*, Janet Ramage, 1997, Oxford University Press).

Now that the concept of energy has been explained, we can move on to kinetic energy.

Kinetic Energy

All moving objects have an energy associated with their motion called kinetic energy (KE). Kinetic energy is the energy of motion (the word ‘kinetic’ itself comes from the Greek word *kinetikos* meaning ‘to move’) and is related to the mass of the body and its velocity. It is measured in joules and its formula is

$$KE = \tfrac{1}{2}mv^2$$

where m is the mass (in kilograms) of the object and v is the velocity (in metres per second) of the object. The ½ factor is a constant and need not worry us. The equation is telling us that if you multiply the mass of the moving body by its velocity, then multiply by the velocity again, then multiply by one half you will get its kinetic energy (KE = mass x velocity x velocity x ½).

Two key points can be discerned from this equation:

1. The relationship between KE and mass is linear, i.e. when the mass of the body is doubled the KE doubles.

2. The relationship between KE and velocity follows a square law, i.e. when the velocity of a body is doubled the KE quadruples (2 x 2). When the velocity of the body is tripled, the KE increases nine-fold (3 x 3).

So when performing a punch or kick, the faster the technique is performed the more effective it will be. If a punch is thrown that travels at 30 metres per second, it will be four times as effective as one travelling at 15 metres per second, as it has four times the kinetic energy. It is the kinetic energy of the punch or kick that breaks a board or causes injury to an opponent.

But where does this KE come from, and where does it go when breaking a board, for example? The body uses chemical energy to contract the arm muscles in order to perform the punch (see figure 1). This chemical energy converts into KE as the arm moves for the punch. When the fist strikes the board it will either:

1. Break the board, in which case the KE from the punch goes into breaking the board (the KE being transformed into sound energy, the subsequent KE of the two halves of the board and a small amount of heat – see figure 2); or

2. Not break the board, in which case the KE of the punch is converted into some sound energy, but is mostly absorbed by the fist and arm joints in the form of thermal energy that causes minor damage, which is registered as pain.

Fig 1

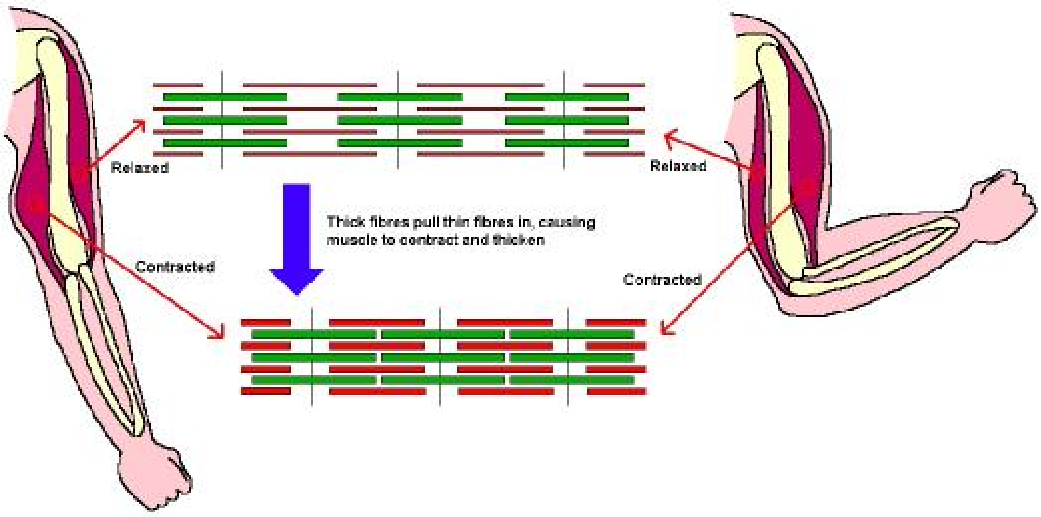
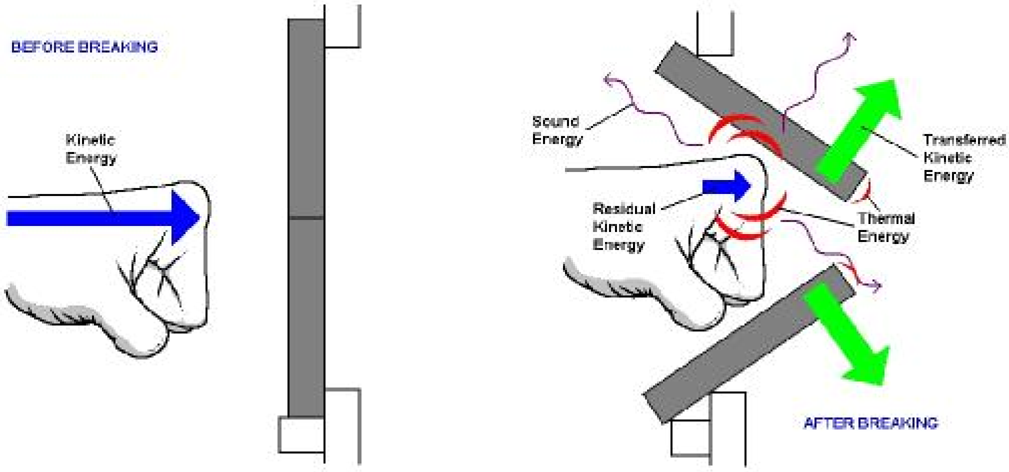


Fig 2



Power

The popular definition of this term is not accurate when compared with the correct physical definition (indeed, in my introduction I use the term in an incorrect way). Power is the transfer of energy over time and is measured in watts (W, joules per second). Punching a brick wall hurts a lot more than punching a sponge because the time taken to dissipate the energy when punching the sponge is much larger, therefore giving a smaller energy transfer, i.e. less power.

I will cover more fundamentals of physics in part two. If any Vision students have any questions abut the physics of Taekwon-Do then please feel free to ask me in class.