THE PHYSICS OF KARATE STRIKES

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1 Introduction

In recent years, the ancient eastern art of Karate-Do (a Japanese word, literally translated as “the way of the empty hand”) has become popular in the western world. Karateka—practitioners of Karate—often break boards, cinderblocks, and other solid materials in order to demonstrate the strength that their training develops. Much can be said of the history and culture associated with the expansion of martial training, but this essay—it is, after all, a physics paper—will examine the collision mechanics of a hand strike to a solid target like a board.

2 Force, Momentum, and Deformation Energy

That large objects moving at high speeds hit harder than smaller objects moving more slowly goes without saying. In attempting to break a board, a karateka seeks to hit the board as hard as possible. It therefore follows that the karateka should move his or her weapon (for the purpose of this paper, the hand) as quickly as possible in order to hit as hard as possible. But what makes for a “hard” strike? Two ways exist to answer this question, both equally accurate. The first looks at the collision in terms of **force** and **momentum**; the second looks at the collision in terms of **energy**.

Force (F) is **acceleration** (a) times mass (m): $F = m\cdot a$. Momentum (p) is mass times **velocity** (v): $p = m\cdot v$. Since acceleration measures change in velocity over time (t) (put another way, acceleration is the derivative of velocity with respect to time), force is the derivative of momentum with respect to time. Equivalently, force times time equals change in momentum, or **impulse** (Δp): $\Delta p = F\cdot t$. This is significant because momentum is a conserved quantity. It can be neither created nor destroyed, but is passed from one object (the hand) to another (the board). The reason for this conservation is Newton’s third law of motion, which states that if an object exerts a force on another object for a given time, the second object exerts a force equal in magnitude but opposite in direction (force being a vector quantity) on the first object for the same amount of time so the second object gains exactly the amount of momentum the first object loses. Momentum is thus transferred. With Δp a fixed quantity, F and t are necessarily inversely proportional. One can deliver a given amount of momentum by transferring a large force for a short time or by transferring small amounts of force continuously for a longer time.

Why, then, move should the karateka swing his or her hand with as much velocity as possible? Because if the hand is moving quickly, it is likely to decelerate (strictly speaking, accelerate in the direction opposite to its direction of travel) more quickly in response to the force the board exerts on it upon collision, as per Newton’s third law. If the amount of time involved in the transfer of momentum is therefore small, the amount of force that will be transferred to the target all at once will be large. This sudden transfer of a lot of force causes the part of the board that is struck and which therefore experiences that force to accelerate. If that part of the board accelerates enough relative to other parts of the board (which are generally held still by the cinderblocks on which the boards are placed), breakage occurs.

This same phenomenon can be analyzed in terms of **energy transfer** and resulting **deformation damage**. Given and object with mass m_1 at rest (the board) and another object of mass m_2 (the karateka's hand) moving at velocity v upon impact and ignoring the negligible amount of energy lost as thermal energy (heat), the amount of energy in the system lost to deformation damage (ΔE) is given by the following:

$$\Delta E = \frac{(1-e^2)}{2} \cdot \frac{m_1 \cdot m_2}{(m_1 + m_2)} \cdot v^2$$

where e is the coefficient of restitution, which measures how elastic the collision is. It is a function of the hardness or softness of the colliding objects, which along with velocity determines impulse. If hard objects collide (for a perfectly inelastic collision, e=0), they will accelerate one another quickly, transferring a large amount of force in a small amount of time while soft objects colliding (for a perfectly elastic collision, e=1) transfer smaller amounts of energy to one another for longer periods of time. Difference in how long momentum takes to transfer and therefore in force at a given instant is why hitting a pillow with the fleshy part of the hand hurts much less than hitting a brick with the knuckles.

As ΔE is proportional to the square of velocity, the more velocity the hand has, the more energy will be transferred into the board. In the simplest possible terms, if the board is infused with more energy than its structure can handle, it breaks. More rigorously analyzed, energy transfer causes the board to dent. This process of transferring energy is **work** (W). Work is force times distance (d): W=F· d. If the area of the board that is struck dents a sufficient distance, it will break. Since the distance it dents depends on the energy transferred to it and the amount of energy transferred depends on the velocity of the karateka's hand, a high-speed strike is most likely to break the board.

3 Striking Surface

Any martial artist who has ever struck a board with improper hand technique can attest to the physical pain associated with such impact. The human had is a complex system of bones connected by tissue, and much can be said about the importance of proper hand alignment in breaking. From the standpoint of physical science, however, what is crucial about hand position upon impact is that all formulae for force, momentum, and deformation energy are for a given unit of **area**. By minimizing the amount of striking surface on the hand involved in collision with the board, a karateka minimizes the area of the target to which force and energy are transferred and therefore maximizes the amount of force and energy transferred per unit area. Consider a martial artist capable of striking with 190 joules (J) of energy. A typical human hand is about 6 inches long including the fingers and 4 inches across, which means that a strike with the entire hand disperses those 190 J over 24 square inches, about 7.92 J per square inch. If, however, the karateka strikes with only the fleshy part of the palm, about 2 inches across and 1.5 inches long, the 190 J will be dispersed over only 3 square inches. That strike will deliver about 63.3 J per square inch, inflicting many times the amount of damage the whole hand could—the same amount of energy dispersed over a smaller area delivers more energy per unit area. This is why martial artists seek to use as tiny a striking surface as possible in not only hand techniques, but also kicks, elbows, and other strikes as well.

4 Point of Focus

Karate black belts often advise white belts before their first attempt at breaking not to try to break the board, but to break the floor under the board. This is to ensure that the hand does not decelerate prior to contact with the target, a mistake that beginners, fearful of injury and therefore mentally hesitant, often make. High velocity of the hand is critical to successful breaking, and data taken from high-speed movies of karateka show that maximum hand velocity is achieved when the arm reaches approximately 75% of extension. Intuitively, this makes sense. Since the hand cannot move forward a distance greater than the length of the arm, it must have a velocity of 0 at full arm's length extension. It follows that the hand must decelerate well before the arm is fully extended. Advising beginners to attempt to hit an imaginary target 25% of their arms' length on the far side of their targets would therefore be more precise than the typical encouragement to aim for the floor, but the physical principle is the same: maximum hand velocity is achieved when the point of focus of the strike is well beyond the surface of the target.

5 Use of Body Mass

Note that **mass** is a co-efficient in the formulae for force, momentum, and energy transfer alike: all three are directly proportional to mass. Since a human being's mass for the time it takes to deliver a strike is constant—a karateka with a body mass of 70 kilograms before a strike will have a body mass of 70 kilograms after the strike—mass is often and erroneously dismissed as a constant in the equations for force, momentum, and impulse. What matters is not the karateka's body mass, but how much of that mass is involved in the strike. A body mass of 70 kilograms is beyond the karateka's immediate control; how many of those 70 kilograms contribute to the strike is very much within the karateka's control. It is therefore crucial not to use the arm alone to extend the weapon and hope for sufficient force and energy to break the target. The entire body should be used by snapping the hips and pushing with the legs in the direction of the target. This explains why boxers are seldom knocked unconscious by jabs, where little more than the mass of the arm contributes to the punch, but are frequently knocked out by hook punches where the entire mass of the body is thrown behind the punch. The same principle of using the entire body mass to deliver a blow applies in breaking techniques as well.

6 Specifics of Impact

Consider now the breaking process from the perspective of the target. When the force of the strike is applied to the board or cinderblock, it accelerates in response to that force. The key is that it does not accelerate uniformly—those areas where the force is applied (the center of the target, if the strike is properly aimed) accelerate much more than the outer regions of the target which are held in place by large cinderblocks. This localized **strain**, the response to influence of **stress** imposed by the strike, initiates the rupture. Strain is functionally the loss of height of the target that occurs when the top surface is compressed and the bottom surface stretched. Because of their molecular compositions, materials such as wood and cinderblocks withstand compression better than stretching. This is why the target begins to split at the bottom. A clean break occurs when the crack reaches the upper surface of the target.

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THE PHYSICS OF IN-LINE SKATING

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In-line skating, or rollerblading, is a popular mode of transportation and a fun pastime. As an avid rollerblader, I have always been interested in the physics behind the exercise. The behavior that governs rollerblading and the person wearing the skates can be explained through the application of classical mechanics or Newton’s laws of motion. The concepts involved in the behavior of rollerblading are: various forces, friction and drag, potential and kinetic energy, the conservation of energy, acceleration and linear and angular momentum.

These concepts can be applied to the behavior of the person and the skates under the general conditions involved in starting from rest, continuous motion, or turning and stopping. Because no two people are created exactly alike, one must also consider that the behavior explained by the laws of mechanics is dependent upon how the mass and body shape of the given individual affects her momentum and the air resistance she will encounter while skating. The design of the rollerblades, too, may play a role.

What causes a person wearing rollerblades to start forward when she is at rest? In order for the in-line skater to begin moving, he or she must experience a force in the direction of motion which causes her to accelerate from rest to some velocity. An in-line skater at rest is only exerting a force down upon the ground (gravity) and the ground is exerting an opposite but equal force up on the skater. This is a simple application of Newton’s third law. However, to begin to accelerate, the body itself needs a force. The acceleration of an object is directly proportional to the force applied to it. The skater uses her leg muscles to apply this force. The skater converts potential energy in the form of stored chemical energy (provided by the food a person consumes) into kinetic energy. The rollerblader shifts her center of gravity over one leg and pushes off that leg while the other leg is thrust forward and the process is continually repeated. All four wheels of the rollerblade are in contact with the surface. The wheels rotate due to the frictional force (static friction) between the area of the wheels that are in contact with the surface. The static friction exerts torques on the wheels which makes them spin. The force of static friction prevents the two surfaces from starting to slide across each other. The force of friction between the area of the wheel touching the ground is opposite the applied force.

The amount of friction between the two surfaces depends on the characteristics of the surface. The main reason for friction between two solids is that any surface, no matter how smooth, is actually jagged when examined with high magnification. When two surfaces are in contact, they actually touch only at specific points which provide resistance to relative motion. The frictional force is complicated and involves electrostatic forces between atoms or molecules where the surfaces are in contact.

Because static friction produces no thermal energy, all of the work the rollerblader does should become kinetic energy in the skater’s forward motion. In order to eliminate any sliding friction, the rollerblade wheels rotate using a ball bearing system. The wheel is positioned between two raceways which hold the ball bearings. The axle is fitted in place between the two and locked in a lot on the shoe using Allen screws. The hub of the wheel does not touch the axle directly. Instead, the two are separated by the set of balls that turn with the hub. The points of contact between the ball bearings and the hub and the axle experience only static friction. Therefore, the possibility of transferring some kinetic energy to thermal energy is reduced.

The sliding friction problem is also reduced by the use of lubrication. Oil added around the parts fills the holes and forms a thin layer of liquid between the pieces of solid. Then each solid part rubs only on liquid, thereby greatly reducing friction.

As the wheels turn, angular momentum is transferred from the surface to the wheels. The wheels spin in one direction and the surface's (or earth's) rotation changes in the other direction, but because the earth has such a huge moment of inertia, its minimal change in rotation is unnoticeable.

An in-line skater who ceases to use her muscles to keep her body going and coasts instead, relies on momentum to keep moving. Newton's first law states that a body tends to continue in motion in the direction it is going unless acted on by an outside force. Linear momentum is a product of mass and velocity. The faster a rollerblader is moving or the more mass she has, the more momentum she has in the direction of motion. A skater with greater mass must exert more force to achieve the same velocity (momentum) as a smaller skater.

Coasting along a road or down a hill, a rollerblader's speed is limited by static friction between the contact point of the wheels and the surface and aerodynamic drag due to the skater passing through air (due to the viscosity of air). It may also be the case that the wheels do not rotate perfectly and they skip on the surface microscopically resulting in kinetic or sliding friction. Also internally, the ball bearing do not eliminate all of the friction.

Collisions are taking place between the skater and molecules of air and a transfer of momentum is occurring. If the object is small and moves at a low speed, the drag force is proportional to the velocity. However for larger objects moving at high speeds through air, as is the case of a person rollerblading, the drag force is approximately proportional to the square of the velocity.

Aerodynamic drag on the skater is determined by the size and shape of the body area the rollerblader presents to the wind stream. The larger the cross- sectional area of the person facing the wind, the greater the resistive force and the greater the slowing effect. The most significant drag effects result from a difference in air pressure across the skater's body due to turbulent air flow. The rush of air around the rollerblader exerts far more pressure on the person's front than on her back. An in-line skater can reduce the size of her wake and the associated pressure drag by wearing aerodynamic clothing (such as spandex) and leaning down to her waist.

In order for the skater to continue to move forward and not slow down, she must continue to convey stored chemical energy into kinetic energy by using her muscles to apply a force, which results in forward progress. The speed and distance a person can attain is determined by her physical fitness and body type, as well as by the efficiency of the chemical to kinetic energy conversion process.

How does the person rollerblading decelerate and eventually stop? Rollerblades have hard, rubberized brake pad located at the heel of the right skate. A person brakes by tilting the heel of the rollerblade so that the rubberized brake surface comes into contact with the ground surface. The two surfaces experience sliding (dynamic) friction as opposed to static friction. The force of sliding friction is opposite to the direction of motion. The rubberized material is "skidding" across the surface. Thermal energy is produced as the rubber heats up due to the aforementioned friction. The smell of "burnt rubber" is noticeable if one follows closely an in-line skater who has come to an abrupt stop. The two surfaces are exchanging energy as a result of having done work on each other. The two surfaces are pushing on one another and moving relative to one another in the direction of their forces and exchanging energy as an outcome. Eventually, the skater comes to a stop because all of her mechanical energy is converted to thermal energy. Brake pads on rollerblades must be replaced very frequently due to the wear and tear from frictional forces. Particles from the brake pad come flying off due to the forces at the two surfaces' contact points.

The fundamental physics of in-line skating and in line skates is best described by Newton's laws of motion. Further, it is evident that forces of friction are very relevant in the behavior of rollerblades. Forces of friction allow people to walk and run and are necessary for the motion of all wheeled vehicles, such as my in- line skates.

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HOW A CRUISE MISSILE WORKS

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The tomahawk cruise missile can fly a 1000 miles and hit a target the size of a car and is a crucial element of the American weapons arsenal. This paper explains how a cruise missile works. It will focus on the cruise missile's launch, flight, low radar visibility and its guiding systems.

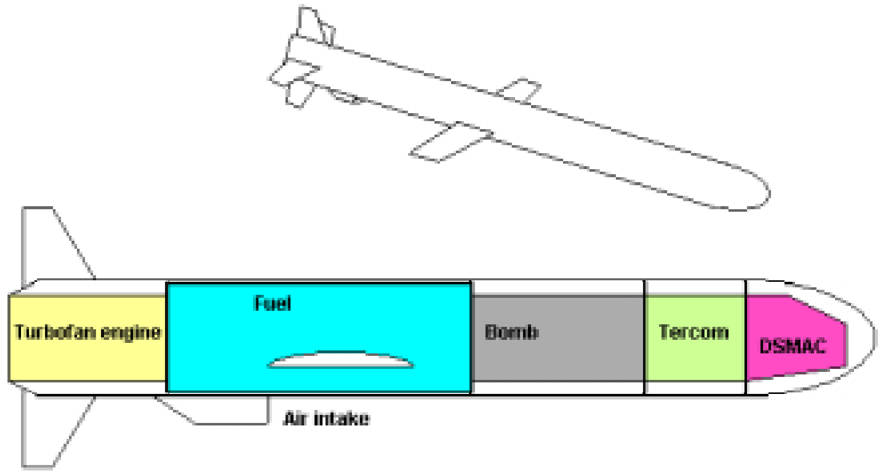

Figure 1

In essence, the cruise missile is a small plane without a pilot. It is 6.25 m long and 0.52 m in diameter. As figure 1 shows, the missile incorporates a turbofan engine, a fuel tank, a conventional bomb, air intake and four different guiding systems. At launch a loaded cruise missile weighs about 1450 kg. A solid rocket booster causes the initial acceleration and launch of the cruise missile. After that the turbofan engine takes over, propelling the missile to a cruising speed of 880 km/h.

The acceleration of a cruise missile and its flight involve Newton's second and third laws of motion. Newton's third law says that "to every action there is an equal and opposite reaction". This law can explain how the solid rocket booster causes the missile's initial acceleration. The propellant in the rocket booster burns very fast and this reaction produces mostly gasses (mainly CO_2). The core of the propellant is hollow and it burns out from the middle so that the gas accelerates through the hollow core out of the back of the solid rocket booster.

The rate at which the burnt propellant gasses come out of the solid rocket booster depends on the difference in pressure between the core of the rocket booster and the pressure outside. The pressure inside the rocket booster is very high as the gas density is high and the gas is hot. In order to increase the booster's efficiency, the nozzle is small. As the gas rushes out of the booster through the small diameter nozzle, the gas accelerates very quickly (this is called the Venturi effect). As the gas accelerates, it converts potential energy into kinetic energy.

The force necessary to accelerate the gas equals the mass of the gas times the magnitude of its acceleration (Newton's second law of motion ($F=m\cdot a$). Although the mass of the gas may not be a lot, therefore, the huge acceleration of the gas causes the force necessary for the acceleration to be substantial. Newton's third law of motion says that a force equal but opposite the force necessary to accelerate the mass of the gas is pushing on the cruise missile and accelerating it. This force accelerates the missile according to $F=m\cdot a$. If the solid rocket booster was completely efficient, therefore, the ratio of the acceleration of the gas and the cruise missile equals the ratio of the weight of the propellant and the missile.

When the solid rocket booster burns out, it falls away and a turbofan engine takes over. At this time, the cruise missile's wings also fold out in order to keep the missile airborne. This process also rests on Newton's laws of motion. In essence, the lift of the wings is base on the same principle as the thrust of the solid rocket booster; they both hurl down gas, so that the reaction force pushes the missile upward. The difference is that the missile's wings use the air around them, while the booster uses the gaseous reaction products of the burning propellant. When the cruise missile's wings "cut" through the air, they redirect air downward. This is acceleration so that the wing must apply force to the air to redirect it. This means that there is an equally large force pushing upward on the wing. This force keeps the missile airborne.

Once in flight the cruise missile has the major advantage that it can fly very low to the ground and evade radar. The physics of radar can explain how this works. Radar uses the reflection of microwaves of objects to determine their location. As all electromagnetic waves, microwaves are composed of an electric and a magnetic field that recreate each other as the wave moves through space. In order to create microwaves, a magnetron sloshes electric charges up and down an antenna (ideally about one fourth of the wavelength). Depending on the frequency of the sloshing, microwaves have wavelengths between 1 mm and 1 m.

When the radar sends out pulses of microwaves, they reflect off metal surfaces back to a detector. When hitting the metal, the microwave pushes on the charges in the metal and accelerates them. These accelerating charges prevent the wave from entering the surface and reflect it instead. A detector picks up the reflected pulses of the microwave and keeps track of time. The time difference between when the signal was sent out and the when the detector picks it up allows the radar-device to calculate how far away the object is located. The distance between the radar and the object equals speed of light ($2.99\cdot 10^8$ m/s) times the time difference divided by 2 (the microwaves have to go back and forth).

The cruise missile evades this kind of detection by flying very low, so that it is invisible to radar. This invisibility has to do with the curvature of the earth, the surface of the earth and the fact that microwaves travel through space in straight lines. If the missile stays close to the ground, the microwaves of the radar cannot reach it, as the wave bounces of mountains and other obstacles. When the cruise missile is even further away (about 100 km), the curvature of the earth can protect it, as the straight microwaves cannot follow the shape of the globe.

During its flight, four different guiding systems guide the cruise missile to its target. Two of these guiding systems will be discussed here. Firstly, during its flight, the cruise missile "knows" how far and where it has traveled through its IGS (Inertial Guidance System). The IGS is based on Newton's first law of motion, namely that an object that is not subject to any outside forces moves at a constant velocity (i.e. that masses have inertia, hence the name). The IGS involves three mutually perpendicular gyroscopes and three mutually perpendicular accelerometers.

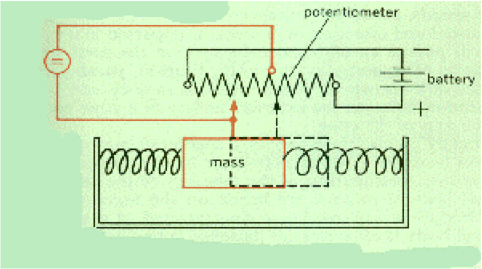

Figure 2

Consider figure 2 depicting the electrical circuit of an accelerometer. The mass is contained between two springs, and connects to a potentiometer (essentially a variable resistor). When the cruise missile is at rest or travels at constant speed, the mass stays at rest and the potentiometer at 0. When the missile accelerates in a particular direction, the mass lags behind, due to its inertia. The potentiometer is set up so that it gives a positive voltage when the missile accelerates and a negative voltage when it decelerates. Based on these voltages, a computer can derive the magnitude and direction of the cruise missile's acceleration and consequently its speed. With this speed and the time, the IGS can calculate how far the cruise missile has flown and in what direction, and consequently its position relative to some reference point.

Due to imperfections in the gyroscopes, however, the inaccuracies of the IGS accumulate over time. The IGS on the cruise missile can be off by up to 900 m per hour! To complement the IGS, the cruise missile is fitted with the Global Positioning System (GPS). This system is based on 24 satellites orbiting the earth. These satellites are positioned so that the receiver on board the cruise missile is able to pick up electromagnetic waves (at both 1575 MHz and 1228 MHz) from more than 4 satellites. From the digital satellite signal, the receiver knows when the satellites sent out the signal. By measuring how long it takes for the electromagnetic waves from the satellites to reach the receiver, it can calculate its distance from that satellite. It uses these distances to accurately determine its position, by a geometrical process called triangulation. The essence of this method is the fact that three spheres intersect at two points at the most. One of these points is usually a ridiculous reading so that that one can be discarded without further measurement. The combination of the distances from the three satellites basically allows the GPS to determine its position relative to the system of satellites. Together with an almanac of where each satellite is at what times, this knowledge allows the GDP receiver to know where its is on earth.

One essential condition for GPS to work is that the clocks in the satellites and the time the receiver uses are very accurate and perfectly in sync. The satellites use very accurate atomic clocks to measure time. The Ce-atomic clocks on board the GPS satellites are based on stimulated emission. Cesium-133 atoms emit a thin microwave spectral line when its 55th electron jumps back from an excited state orbital to its ground state (transition). The atomic clocks on board the GPS satellites use this frequency, $9.192631770 \cdot 10^9$ Hz, to very accurately keep time. As atomic clocks are very big, however, there is no atomic clock in the GPS receiver on board the cruise missile. However, with a fourth reading, the GPS receiver can be largely synced with the atomic clocks on the satellites.

Besides the problem of syncing the clocks, the GPS system has to overcome the fact that the electro-magnetic waves do not always travel at the speed of light. The atmosphere slows down the electro-magnetic wave. However, low frequencies get slowed down more than high frequency signals. The GPS receiver on board the cruise missile detects both signals and measures the difference in how long its took them to reach the receiver. Then the receiver uses this fact to determine how much the atmosphere has slowed down the signals and corrects for.

With the help of GPS, IGS, solid rocket boosters, flight, and radar invisibility the cruise missile delivers its 1000 pounds bomb to its target. Once that job is well done, the explosion of its bomb destroys the million dollar missile. It's ironic that in monetary terms the greatest damage the cruise missile does may often be destroying itself.

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Volume 1 JOURNAL OF HOW THINGS WORK Fall, 1999

CRAFTY CONNIE'S HOT GLUE GUN EXPERIENCE

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Crafty Connie was sitting quietly in the shade of a large oak on the University of Virginia's lawn reading over her anthropology notes. Cool Craig walked smoothly up to Connie and took a seat on the soft grass. Connie could hardly breathe. Here was the boy she had a crush on for two semesters sitting next to her! Craig coolly introduced himself and then asked if she would like to attend a spring benefit dance with him the following Saturday night. Connie barely managed to gasp out a yes, with an emphatic nod. "Wear something springy," he suggested as he walked towards Cabell Hall.

In the next few days, Connie could think of nothing else except her impending date, and the problem of what to wear in order to impress Cool Craig. Her roommate, Stylish Selena, had lent her a beautiful silk flowered spring dress, but Crafty Connie had no idea what to do with her hair. While she was sitting in her room one night, staring at a set of small silk butterflies she had taped to her wall, she had an idea. If there was some way to attach the butterflies to bobby pins, she could put them around a bun in her hair. That would surely do the trick. Cool Craig would think she was the belle of the ball. But how could she get them to stay? Elmers glue would never hold the butterflies and super glue was too risky for something that was going in her hair. What she needed was a hot glue gun.

She hopped in her sporty sedan and drove to Wal Mart. At Wal Mart her eyes were assaulted with all different types of glue guns. She finally settled on a Black and Decker trigger feed hot glue gun. As she settled down in her dorm room to assemble her hair clips, she wondered, "How does such a large, plastic-like rod turn into a thin melted line of glue?" She took the problem to her RA, Phyllis the Physics major, who began to outline the inner workings of the hot glue gun.

Together the two women sat down and began to disassemble the trigger feed glue gun. They realized the hard blue plastic shell of the gun was actually two pieces that could be separated by prying apart the tabs connecting the two pieces. Crafty Connie inserted a small screwdriver in between the two tabs. By using the screwdriver as a lever, she was able to pop the shell of the glue gun open. Phyllis the Physics major decided the easiest way to describe the workings of the glue gun would be to describe the individual pieces before describing the components' relationship to one another.

The first thing they examined was the blue plastic shell. The inside of the shell revealed that it had been molded to hold all the other pieces in their proper positions. The whole gun fit together like the pieces of a jigsaw puzzle. Attached to the whole gun, was a small wire prop that held the glue gun upright while it was warming up. Inside the gun, was a small wire spring connected to a large, orange plastic trigger. A metal pulley was attached to the plastic trigger. This pulley system connected the trigger with a plastic "O" ring that Crafty Connie believed pushed the glue stick into the gun. Another "O" ring was found at the back of the gun, through which the glue stick was initially slipped and held in place.

Directly across from the second "O" ring, Connie and Phyllis found an orange plastic cylinder, which stabilized the glue as it passed into the cast aluminum "oven".

"Connie, from the looks of the glue gun, everything is put together to work off the previous piece. I think you are ready to discuss how this glue gun really works," explained Phyllis. She pointed to the prop that held the glue gun up while it warmed up. "In terms of physics, Connie, this can be seen as a seesaw of sorts."

"How is that?" questioned Connie.

"Well, the weight of the handle is greater than that of the nose of the gun. The prop acts as a metal pivot. The greater weight of the handle forces the handle down, while the nose remains upright. This is the same thing that happens when a heavier child sits on one end of a typical seesaw, while a lighter child sits on the opposite end. In physics, weight is defined as the object's mass multiplied by the acceleration due to gravity. For any object falling near the earth's surface, the downward acceleration is 9.8 m/s^2, no matter what the mass of the object is."

"Okay, I understand how the prop works, but how does the trigger work?" questioned Crafty Connie.

"The plastic trigger of the glue gun is attached to the metal pulley we have already looked at. As your finger does work on the trigger…"

"What do you mean, 'does work'?"

"To "do work" on an object in physics means to exert a force on an object and have that object move in the same direction of that force. When you depress the trigger, the trigger moves down, the same direction as the force you exerted. Since the pulley system is connected to the back of the trigger, when the front of the trigger goes down, the back of the trigger (where the pulley is connected) goes up. The pulley connects the trigger to the "O" ring that advances the glue stick forward. As the trigger goes down, the pulley pulls the "O" ring forward and advances the glue stick into the heating oven. We will exam the oven in a minute."

"Wow Phyllis, I think I understand this. What next?" Crafty Connie questioned.

"Well, as the glue stick is advanced by the "O" ring and the trigger, it moves through the long, orange plastic cylinder I showed you earlier. This cylinder is connected to the cast aluminum oven, and guides the glue stick into the heating chamber. Let's look at that piece next."

Phyllis removed the double-barreled cast aluminum-heating chamber that had been fit into the plastic molded shell of the glue gun.

"The heating element of the glue gun, which we will see is a resistor, is placed in the lower barrel of the chamber that is provided with heat from the electricity provided from the wall socket. In the upper barrel, as the glue stick advances, it passes over this heating element and is melted."

"But how does electricity turn into heat?" questioned Crafty Connie.

"Well, to answer this question, we must first start with the wall plug. The wall plug is made up of two electricity-conducting metal prongs covered in a thick plastic coating. Each prong is attached to a wire, which allows alternating current to flow from the electric company into the glue gun. This alternating current brings positive electrical charges carrying energy through one wire, and deposits the energy on these two metal rods," explained Phyllis, as she pointed to two aluminum rods which she withdrew from the bottom chamber of the heating oven. Between these two aluminum rods, was a flat piece of heat conducting ceramic.

"What does this do?" asked Crafty Connie.

"This piece of ceramic, which acts as a resistor, is sandwiched between the two aluminum rods carrying the positive charges to and from the electrical company. As positive charge and energy is deposited onto the piece of ceramic, the ceramic begins to get warm. Positive charges without energy flow out of the heating system and return to the electrical supply. It is a well-known law in physics that energy can be converted into many different forms, but can never be lost. Do you know how this energy is converted into heat?"

"Well, I don't know, but I'm sure there are equations and explanations for this conversion. Do you know them?"

Phyllis smiled. "Let me see if this helps, Connie. First, you should know that the function of a resistor, which this piece of ceramic is, is to hinder the flow of the electric current and convert some or all of the energy into heat energy. As current flows through a resistor, it loses energy and the resistor becomes warm. More simply put, when a big current loses a lot of voltage, something will get hot."

"What do you mean 'when the current loses a lot of voltage?" asked a puzzled Crafty Connie.

" A resistor is basically two wires that are connected by a poor conductor of electricity, in this case, the sandwiched piece of ceramic. Current flows through the ceramic, a poor conductor, only if there's an electric field moving it forward. The larger the resistance of the ceramic, the less current that flows through it, resulting in a voltage drop. Therefore, the voltage drop equals the voltage before the resistor minus the voltage after the current flows through the resistor. The actual resistance of this ceramic piece, which we cannot measure without the proper equipment right now, would be found by dividing the voltage drop by the current flowing through it. This would be measured in ohms."

"I get it, so for the voltage drop in my glue gun, not much current is carried and this results in heat that melts the plastic, right?"

"Exactly, now you're catching on. There's one more piece here in the lower barrel that we haven't looked at though. It's this hard, plastic cylindrical casing surrounding the two aluminum rods and ceramic resistor. Why don't you try and burn the plastic before I explain its function.

Phyllis handed Connie a lighter and the plastic encasement. Connie held the plastic over the flame for several seconds, but could not get the plastic to flame.

"Why won't it burn Phyllis?"

"Well, just think what would happen if it did, the whole gun could catch on fire. The plastic encasement is a heat conductor. It can withstand high temperatures in order to conduct the heat created in the bottom chamber into the upper chamber. It also protects the heating element from scraping against the inside of the cast aluminum-heating chamber.

Connie picked up the double-barreled heating oven and inserted the two aluminum rods with the ceramic sandwiched between back into the plastic encasement and back into the lower barrel.

"So the electricity is carried from the wires into the two rods where energy is deposited and converted into heat because of the voltage drop caused by the ceramic resistor. This heat is then transferred to the upper chamber by the plastic conductor, and that melts the glue in the upper chamber, right?"

"That's correct. Now can you tell me what this material surrounding the entire heating unit would be for?" quizzed Phyllis the Physics major.

"Well, I guess it protects the plastic shell from the heat. Since the oven is made out of a metal that would conduct the heat, wouldn't it melt the shell if there was nothing between the oven and the plastic shell?"

"Yes, it would. This white material is wrapped around the oven and is what we call an insulator. It is made of woven glass fibers that resist the propagation of heat. Glass is a poor conductor of heat anyway, but by reducing it to an entanglement of fibers, it makes it even harder for the heat to get through. It is difficult to explain how insulators work without a firm understanding of an atom's nucleus. An atom's nucleus has a set of valence and conduction levels through which electron's move. In an insulator, the set up of the valence and conduction levels prevents the movement of electrons. Hence, in the case of the glue gun's insulator, the glass fiber material, the insulator keeps the thermal energy away from the shell."

"I think I understand what you are saying. I am glad the insulator is made of those long strings of glass to trap the heat, because the box says the gun can get up to 380 degrees Fahrenheit, and I wouldn't want to burn my hand."

" Here," said Phyllis, "try to burn it with that lighter I gave you."

Connie held the insulator up to the flame for several seconds. The insulator did not flame, but the outer layer scorched.

"Now see how the insulator did not burn, Connie. It would have melted if you left the flame on it long enough, but it will not catch on fire. It is performing its intended purpose."

"I see, so if I left the gun on for too long an extended period of time, the insulator could melt and cause the gun to malfunction, right?"

Phyllis nodded her head, and said, "That's why you have to unplug it after every time you use it. The last part we need to discuss is the nose of the glue gun."

"The shape of the nozzle reminds me of the funnel my mom uses when putting gasoline into our lawn mower."

"Very observant. The glue is melted by the heat coming from the bottom chamber and conducted by the plastic heat-conducting encasing. However, the glue is not much use as a large blob, so it needs to be made into a thin, workable line of glue. By gradually decreasing the diameter of the nozzle, it can be made to come out of the small opening at the end of the nozzle in this thin workable line of glue. This is how you can use such a large plastic rod to affix your butterflies onto the thin bobby pins. What good would a large thick blob of glue be? This way, you do not need to manipulate the blob into something usable. The glue gun does it for you. Do you understand?"

"I think so, let me see if I can briefly explain what you just told me," said Crafty Connie. " The prop attached to the outside of the plastic shell acts as a pivot. Since the side of the gun with the handle and trigger is heavier, the nozzle points up. As I do work on the trigger by pushing it down, the trigger does work on the pulley, then pulls the "O" ring forward. The "O" ring advances the glue stick into the orange plastic cylinder that stabilizes the glue stick as it enters the upper barrel of the heating unit. Alternating current from the power company flows into the plug and through the wires. The current enters with a positive charge with energy and leaves with a positive charge with no energy. The energy is deposited on to those two aluminum rods. The ceramic piece sandwiched between the two rods acts as a resistor. This resistor creates a voltage drop that results in the production of heat. The heat is then conducted by the plastic encasing into the upper chamber, melting the glue. The entire chamber is surrounded by the glass fiber insulator, which keeps the outer shell from melting. The final step is for the melted plastic to pass through the nozzle into a thin workable stream of glue. Did I get it right?"

"Yup, those are the basics of your glue gun. Now, I guess we need to put this back together, or how else are you going to glue those butterflies on?"

Satisfied with her understanding of the glue gun, Connie smiled and nodded her head. Crafty Connie and Phyllis the Physics major reassembled the glue gun.

“Thank you so much for your help Phyllis. I should probably go try and assemble my hair clips before I go to bed. The dance is tomorrow. I don’t want to wait till tomorrow and have anything go wrong.”

“No problem Connie. I think that is a good idea. Have a great time at the dance, and I’m sure everything will work out okay. Feel free to come back with any questions. Make sure you let the glue cool, so it sets back into the hard plastic and sets the butterflies onto the bobby pins. Good night, I’m glad I could help,” concluded Phyllis

The next night, Phyllis watched from her open door, as Cool Craig walked slowly up to Crafty Connie’s door and nervously knocked. Connie answered the door in Stylish Selena’s flowing dress, her hair adorned with several small butterflies, successfully attached to small bobby pins. “Wow, you look beautiful. How’s you get those butterflies to stay?” marveled Cool Craig.

“Oh, my RA helped me. It actually wasn’t nearly as hard as I had thought,” explained Crafty Connie. She winked over Cool Craig’s back at Phyllis the Physics major as they walked, hand in hand, out the door. Phyllis smiled and shut the door. Later that night, she saw Craig return a smiling Connie to the dormitory, with butterflies still dancing on her head.