Lesson: The Physics of Music
STANDARDS: **California**

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:
    a. *Students know* how to solve problems that involve constant speed and average speed.
    b. *Students know* that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law).
    c. *Students know* how to apply the law F=ma to solve one-dimensional motion problems that involve constant forces (Newton's second law).
    d. *Students know* that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).
    e. *Students know* the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth.
    f. *Students know* applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).
    g. *Students know* circular motion requires the application of a constant force directed toward the center of the circle.
    h. * *Students know* Newton's laws are not exact but provide very good approximations unless an object is moving close to the speed of light or is small enough that quantum effects are important.
    i. * *Students know* how to solve two-dimensional trajectory problems.
    j. * *Students know* how to resolve two-dimensional vectors into their components and calculate the magnitude and direction of a vector from its components.
    k. * *Students know* how to solve two-dimensional problems involving balanced forces (statics).
    l. * *Students know* how to solve problems in circular motion by using the formula for centripetal acceleration in the following form: $a=v^2/r$.
    m. * *Students know* how to solve problems involving the forces between two electric charges at a distance (Coulomb's law) or the forces between two masses at a distance (universal gravitation).

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:
    a. *Students know* how to calculate kinetic energy by using the formula $E=(1/2)mv^2$.
    b. *Students know* how to calculate changes in gravitational potential energy near Earth by using the formula (change in potential energy) =mgh (h is the change in the elevation).
    c. *Students know* how to solve problems involving conservation of energy in simple systems, such as falling objects.
    d. *Students know* how to calculate momentum as the product mv.
    e. *Students know* momentum is a separately conserved quantity different from energy.
    f. *Students know* an unbalanced force on an object produces a change in its momentum.
    g. *Students know* how to solve problems involving elastic and inelastic collisions in one dimension by using the principles of conservation of momentum and energy.
    h. * *Students know* how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.

4. Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:
    a. *Students know* waves carry energy from one place to another.
    b. *Students know* how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).
    c. *Students know* how to solve problems involving wavelength, frequency, and wave speed.
    d. *Students know* sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.
    e. *Students know* radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately 3×10^8 m/s (186,000 miles/second).
    f. *Students know* how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler Effect, and polarization.

Exploring Physics through Music

***Motivation*:** Ask students to make a list of activities they do that would be impossible without the application of physical principles. Give them the example of crossing the street. If students did not have the built in ability to estimate rates, they might be run over every time they cross! Encourage them to think about specific parts of objects they use throughout the day. How does playing a sport use momentum? How does driving a car use the principle of inertia?

***Group Activity*:** Watch *The Piano Action* and *The Piano Pedals* under the *The Piano* e-respentation in *At the Piano with Alan Gampel*. Ask students to make a list of ways in which physical principles are applied to create the piano's sound. Ask each group to focus on a different part of the piano. One group might focus on pedals. Another may focus on the hammers. Still another may focus on the type of wood. Here is an example of a list a student might make about the hammers:

1) Waves – the hammers hit the strings which create waves which produce sound
2) Waves – the strings only vibrate for a short period of time
3) Waves – the strings have different frequencies, creating different sounds
4) Inertia – hammers start the strings then stop them because no new motion is created
5) Inertia – the key has to trigger the hammer, so the strings are stopped until force is used
6) Kinetic energy – kinetic energy is necessary to trigger the strings
7) Potential energy – potential energy is what the strings have before they are struck

For further practice, students may repeat the exercise while viewing *The Trumpet* under *Jazz with Wynton Marsalis.*
As a class, come up with a list of problems one might find in a physics textbook using the piano as the basis of the questions. What formulas are involved? What physical principles affect the sound?

***Independent Activity*:** Have students pick instruments. Remind them that the voice is also an instrument. Encourage them to pick instruments from around the world. Encourage students to investigate instruments they play or aspects of music they enjoy listening to. Tell students they will be making presentations on these instruments to the class. The presentation must consist of two parts. First, the students must talk about the physical principles involved in using the instrument to create sound. During this part of the presentation, students must provide sound samples. Second, the students must develop a problem set of five to ten questions, which the class will do after their presentation. Students may do multimedia presentations and work in groups.