Lesson Title	Spacecraft MMOD Shielding
Length of Lesson	At least 4 hours
Created By	Justin Warren
Subject	Physics
Grade Level	11-12
State Standards	Physics: 1a,b,c,d,e
DOK Level	DOK 3
DOK Application	Develop a Logical Argument, Explain Phenomena in terms of concepts
National Standards	Science as Inquiry A
Graduate Research Element	The researcher focuses on novel spacecraft shielding configurations and materials.

Student Learning Goal:
The students will be introduced to the idea of MMOD (micrometeoroid and orbital debris) shielding for spacecraft. They will visit the Mississippi State University hypervelocity impact lab and micro two-stage light gas gun. In the process they'll be exposed to current research efforts.

State Standards
Inquiry 1: Apply inquiry-based and problem-solving processes and skills to scientific investigations.
a. Use current technologies such as CD-ROM, DVD, Internet, and on-line data search to explore current research related to a specific topic. (DOK 3)
b. Clarify research questions and design laboratory investigations. (DOK 3)
c. Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations (e.g., hypotheses, experimental design, observations, data analyses, interpretations, theory development). (DOK 3)
d. Organize data to construct graphs (e.g., plotting points, labeling x-and y-axis, creating appropriate titles and legends for circle, bar, and line graphs) draw conclusions and make inferences. (DOK 3)
e. Evaluate procedures, data, and conclusions to critique the scientific validity of research. (DOK 3)
f. Formulate and revise

National Science Education Standards of Content 9-12
A: Science as Inquiry
Results of scientific inquiry - new knowledge and methods - emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to

obtain evidence must be clearly reported to enhance opportunities for further investigation.

Materials Needed (supplies, hand-outs, resources):
Access to scholarly journal publications, access to a two-stage light gas gun laboratory

Lesson Performance Task/Assessment:
The students will visit the MSU hypervelocity lab to learn about spacecraft MMOD (micrometeoroid and orbital debris) shielding and to see how those impacts are simulated. Before the trip to MSU, each student will be asked to find one or two scholarly journal publications which deal with hypervelocity impact experiments or spacecraft MMOD shielding that they find interesting. From these articles they'll each suggest two shielding configurations to be tested during the visit. The instructor will choose and construct two targets based on the class' suggestions and available materials.

The students will arrive at the lab in the morning where they will be introduced to the micro two-stage light gas gun and its operation. Then they'll aid the instructor in preparing the gas gun to be fired for the first target while discussing the concepts behind the experimental setup along the way. Once the gun is fully prepared, the students will leave the lab to tour other research facilities on campus and have lunch. This break is necessary because the light gas gun requires several hours to pull a complete vacuum inside the projectile flight tube. While the students are gone, the first target will be shot and the second target prepared.

Upon returning to the lab, one lucky student will be chosen to physically fire the light gas gun. Then the second target will be removed for comparison with the first. The students will be in charge of calculating the impact velocities and kinetic energies based on the data taken during the experiments. Finally, the students will aid the instructor in shutting down the light gas gun.

Lesson Relevance to Performance Task and Students:
The students will learn about academic research first hand, not only by visiting a lab in person, but also by investigating the relevant literature on their own. From this lab they should gain an understanding of how scientific research takes place.

Anticipatory Set/Capture Interest:
They'll see the experimental setup right away, which should prove interesting. If that doesn't do it, being away from school on a college campus should take care of capturing interest.

Guided Practice:
The instructor will take some time during the previous lab session to introduce the topic of spacecraft shielding and hypervelocity impacts. During this introduction the students

will be introduced to the basic concepts and will be instructed to find one or two scholarly publications they find interesting which deal with the topic. Based on these, they'll be told that each student should suggest two shielding configurations. During the lab visit, the instructor will guide nearly the entire lab.

Independent Practice:
The students will have time to consider their shielding configuration suggestions after class, and any calculations will be performed by the student.

Remediation and/or Enrichment:
Remediation: Individual IEP

Enrichment: If there is extra time, the students might investigate their impacted specimens using optical microscopy.

Check(s) for Understanding:
The student should have a good idea of what goes into university level research in terms of specificity of topic, review of literature, importance of data acquisition and measurement, just plain long hours of work for students, etc…

Closure:
Following the experiment, the instructor will discuss the damage to the impacted specimens with the class as well as where the instructor's own personal research is headed and how that will contribute to science and industry. They'll also be asked to address the validity of testing shields meant for the space environment inside earth's atmosphere.

Here are some provocative questions to ask the class:

- In your opinion concerning sacrificial spacecraft shielding, is added volume or added weight more important and why?
- Why are impacts at hypervelocities different from those at lower velocities?
- Why is the idea of a multifunctional material important for space applications?

Possible Alternate Subject Integrations:
Space environments

Teacher Notes:
A lesson like this could be done for any type of university research. Just contact a lab at a nearby university that sounds interesting and set-up a visit. Most research programs have an outreach component and would be glad to accommodate bright students.