Low-Z Opacity Measurements

White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 19, 2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)**

- ***Describe the research frontier* and importance of the scientific challenge.**

A frontier in high-energy-density physics (HEDP) exists in measuring the opacity of low-Z ($Z < 13$) elements. Plastics are very commonly used in high-energy-density (HED) experiments, are often combinations of hydrocarbons and other low-Z elements (*e.g.*, O, N). Accurate knowledge of opacities of these materials is essential for understanding radiation transport and heating, which dictates how the system will evolve. These materials are also important in the field of solar physics, where there currently exists a debate over the abundances of elements with $Z > 2$ in the solar interior. Previous experiments attempted to study the opacity of plastics[1-7] but they were unsuccessful due to density and temperature gradients, which complicated the analysis.[3] Recent technological advances in high-intensity radiation sources, target design and material fabrication techniques, and diagnostic capabilities now make it possible to experimentally measure opacities over a wide range of densities and temperatures that are relevant to the conditions found in the interior of the sun and to those found in ignition.

The choice of carbon opacity model can give rise to the formation of different features, such as double ablation fronts.[8] The addition of dopants to ignition capsules only complicates our understanding of the opacity. Recently, it has been determined that glow-discharge polymer (GDP) capsules pick up oxygen[9] and the presence of the oxygen would increase the opacity of the ablator material thereby changing the radiation transport. Although GDP opacity experiments have been mentioned,[10] to the knowledge of the authors, these results have not been published. New calculations of the opacity of low-Z materials such

as C and O have recently been published[11] but there has been no data to compare to the calculations. Figure 1 plots the carbon opacity for three different models at 0.2 g/cm^3 and a temperature of 200 eV. Opacity differences of up to 50% can be seen in the valleys between the lines.

Knowledge of the sun provides the basis of our understanding for every other star. Yet in significant ways the sun is poorly understood. In recent years, there has been a debate over the abundances of heavy elements ($Z > 2$) in the solar interior. Recent solar atmosphere models[12] find a significantly lower abundance for C, N, and O compared to models used roughly a decade ago. Although the models used now are far more sophisticated than before, a discrepancy still exists between fully-evolved solar models that use the updated abundances and solar properties inferred from helioseismic measurements and also from neutrinos.[13]

The only way to solve this discrepancy is to perform experiments in the appropriate temperature and density domain and provide data to validate the current opacity calculations. All the different groups working on this field are in agreement that one needs to solve the problem because if we have some doubt on the Sun we will have difficulty extrapolating to other stars for which less information exist.

Recent measurements of Fe at solar-relevant conditions were performed and a large discrepancy between the experiment and the opacity models exists.[15] These results have been questioned on theoretical grounds[16] however, there is still not a conclusive answer to the discrepancy in these experiments. These results are surprising because the data from previous experiments at lower densities and temperatures were matched by the opacity models and because of the magnitude of the difference. In addition, large differences exist in regions of continuum emission, where one might expect the models to have more success. These results raise the question, if there is a discrepancy with iron, is there a discrepancy with other elements under these high density and high temperatures?

Starting in 2012, experiments were performed by LLNL to study the opacity of silicon.[14] The initial results did not agree well with opacity models for silicon. Improvements to the experiments have resulted in better agreement between the opacity models and the experimental data for the n=1 and n=2 transitions, but they suggest non-LTE physics or sample nonuniformities may be present. Discrepancies still exist between the opacity models and the data for high-n transitions.

Dedicated experiments to study the opacity of low-Z ($Z < 13$) materials would provide data to test the opacity models in a regime relevant for high-energy-density experiments. The recent LLNL silicon and Sandia iron opacity experiments have shown that although the opacity models may agree well between themselves, they do not always agree with the data. These experiments have also shown that the disagreements with the models are not necessarily where one might expect, (i.e. with the spectral lines), but exist in the valleys between the lines and in regions of the continuum where the models are expected to have better agreement. Experiments of low-Z materials will provide additional data to see if this disagreement continues. Also, the low-Z materials should be easier to model, since there are less electrons than some of the previously studied materials and may shed light on if the discrepancies are associated with specific elements or are a general issue in opacity models.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

In order to advance this frontier, a platform for low-Z opacity measurements must be developed. The platform will involve experiment, radiation-hydrodynamic simulations and opacity models. We will evaluate different designs with simulations, converging on the platform with the least density and temperature gradients. We will execute experiments, measuring the absorption spectra and then comparing it the predicted spectrum from the opacity models. We will iterate on the experimental design if the experimental results such larger gradients than the simulations predicted. In particular, a choice of tamper must be made. Since we want to study elements such as C, N and O, we cannot use plastics as the tamper, as they contain these elements and will greatly complicate the analysis because gradients will be present. Be is being explored as a choice.

In the high energy density community, there exist very few low energy (< 1000 eV) spectrometers with high spectral resolution. Those that exist are transmission grating spectrometers with resolutions of >10 eV. A crystal spectrometer with spatial resolution better than 25 microns and spectral resolution better than 5 eV would provide the necessary resolution to obtain high-quality absorption spectra to further our understanding of the opacity of these materials.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit***.

This research will provide opacity data on elements under conditions that have not been studied before. With discrepancies found in the Bailey work[15] and the older Heeter work,[10,14] additional data to test the opacity models would be valuable in uncovering any issues. Dedicated opacity experiments on low-Z materials would provide important data to test these models.

A better understanding of low-Z opacity will help answer the questions raised concerning opacity models for ignition targets.[8] These experiments are valuable for the solar physics community as well. Providing opacity data in the appropriate density and temperature regime will allow one to test the opacity models and determine if, as some has suggest, the cause of the disagreement in the abundances of the heavy ($Z > 2$) elements is due to an opacity issue. This data will be extremely valuable because regardless of whether it agrees with current models or not, it will help define a path forward in resolving the solar abundance discrepancy.

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Figures (maximum 1 page)

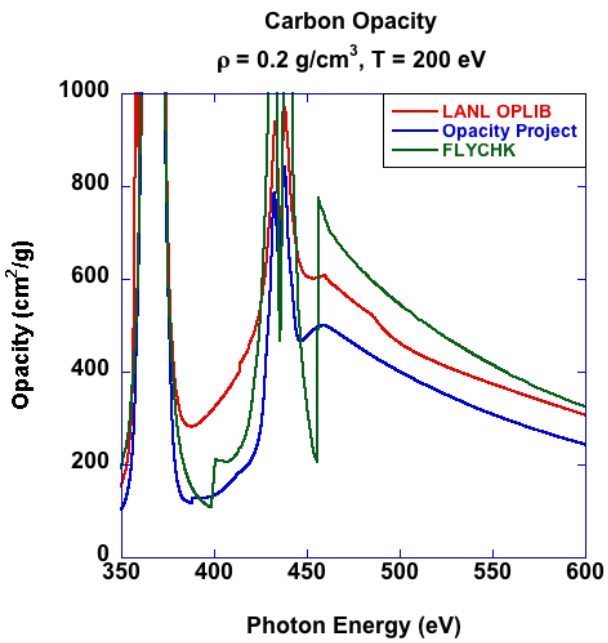

Figure 1: A comparison of the LANL OPLIB (red), Opacity Project (blue) and FLYCHK (green) opacity models for carbon with a density of 0.2 g/cm^3 and at a temperature of 200 eV between photon energies of 350-600 eV.