**SOUND VELOCITY, DENSITY, PHASE DIAGRAM, AND EQUATION OF STATE OF IRON-PHOSPHORUS LIQUIDS UNDER PLANETARY CORE CONDITIONS.** J. Chantel[1], Z. Jing[1], T. Yu[2] and Y. Wang[2], [1]Department of Earth, Environmental, and Planetary Sciences, Case Western Reserve University, Cleveland, OH 44106, julien.chantel@case.edu, [2]Center for Advanced Radiation Sources, The University of Chicago, Chicago, IL 60637.

**Introduction:** Liquid Fe is the dominant component in the Earth's outer core and possibly the cores of other terrestrial planets like Mars and Mercury. Geophysical and geochemical observations suggest that light elements such as S, C, Si, P, O, etc., are likely present in the molten Fe cores [1]. In order to determine to the abundance of each light element, it is crucial to determine the equation of state for Fe-X (X=S, Si, C, P, O, etc.) alloying liquids under the conditions of planetary cores. Phosphorus could be an important light element candidate in planetary cores because of the abundance of iron phosphides minerals in meteorites, such as schreibersite ($Fe_3P$) [2], allabogdanite ($(Fe,Ni)_2P$) [3], and perryite ($(Ni,Fe)_8(Si,P)_3$) [4]. However, currently available data on the density of Fe-rich liquids are very limited in pressure and composition, and thus are insufficient to constrain the equation of state at pressures relevant to planetary cores due to the strong trade-off between bulk modulus and its pressure derivative. In this work, we carried out density and sound velocity measurements of liquid Fe-P alloys. Ultrasonic velocity measurements provide direct constraints on the bulk modulus of a material at high pressures and thus can significantly improve the fitting of the equation of state. In addition, sound velocities of Fe-X liquids can also be directly compared to seismic wave velocities (when available) to constrain the light element abundances in planetary cores. We also conducted in-situ density measurements on liquid Fe-P using the X-ray absorption technique. The density data obtained in these experiments help to quantify the effect of light elements on core density and further constrain the core compositions of the terrestrial planets such as Mercury, Mars, and the Earth's Moon.

**Experimental Data:** *Sound velocity measurements:* We conducted ultrasonic sound velocity measurements on $Fe_3P$, Fe-5wt%P, and Fe-10wt%P liquids using the T-25 module at GSECARS beamline 13-ID-D, APS (Chicago) (Fig. 1). Ultrasonic sound waves were generated and received by a transducer attached to the back of an anvil. A buffer rod was placed between the sample and the anvil to ensure the perfect contact and impedance contrast. A waveform generator and a digital oscilloscope were employed for waveform generation and recording. Travel times of the ultrasonic waves through the sample were determined by the pulse echo overlap method using reflected signals from the buffer rod/sample and sample/backing disk interfaces. Sample length was determined by X-ray radiographic imaging. Then the sound velocities of the liquids are calculated from the travel times and sample lengths. We use dual-mode $LiNbO_3$ transducers with the P-wave resonant frequency at 50 MHz. Pressure and temperature conditions of the experiments were about 1-7 GPa, and 300-1973 K. Pressure of the experiments was determined by the energy dispersive X-ray diffraction of the MgO pressure standard. Temperature was monitored by a W5Re-W26Re thermocouple.

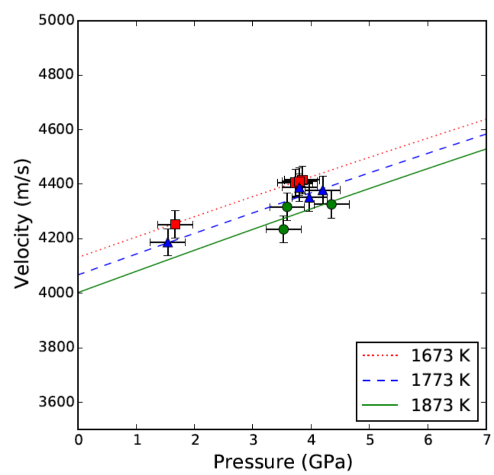


Fig. 1. Sound velocity results for $Fe_3P$ liquid

*Density measurements:* We conducted X-ray absorption experiments on liquid $Fe_3P$ using a DIA-type cubic-anvil module in the 250-ton large volume press at GSECARS beamline 13-BM-D, APS (Chicago) (Fig. 2). Pressure and temperature conditions of the experiments are 1-7 GPa, and 1473-2173 K. MgO and BN mixture were used as the pressure standard. Temperature was measured by a W5Re-W26Re thermocouple. A CCD camera was used to measure intensities of transmitted monochromatic X-rays through molten samples, with the photon energy optimized at 40 keV. We made important technical improvements in determining X-ray absorption profiles by combining imaging with sample scanning, to ensure beam homogeneity and remove background scattering. The densities were then determined from the Beer-Lambert law using the mass absorption coefficients, calibrated by comparing the X-ray absorption density with the X-ray diffraction density for the $Fe_3P$ solid before the sample was molten.

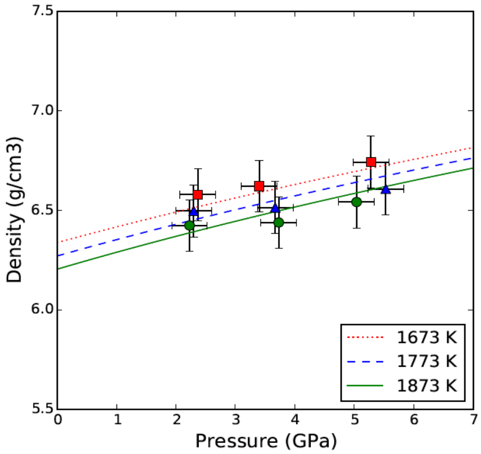

Fig. 2. Density results for $Fe_3P$ liquid

*Phase diagram determination:* We have successfully determined, at pressures up to 7 GPa, the temperatures of both solidus and liquidus of $Fe_3P$ and Fe-5wt%P, using ultrasonic wave velocity measurements in multi-anvil apparatus (Fig. 3). During the heating of the experiment, we observe the solidus through the change of the P-waves signal when the sample is partially molten, and the liquidus through the phase shift of the sample of the signal from the liquid when the sample is entirely molten. Those observations have been confirmed during in-situ synchrotron experiments using the ultrasonic measurements in conjunction with X-ray diffraction at the GSECARS Beamline 13-ID-D. In fact the ultrasonic interferometry allows to determine the solidus and liquidus temperatures more precisely than the X-ray diffraction.

**Discussions and implications:** Sound velocity data for all three Fe-P compositions ($Fe_3P$, Fe-5wt%P, and Fe-10wt%P) were obtained. Figure 1 shows the results for $Fe_3P$ as an example. The measured velocities of Fe-P liquids increase with compression and decrease slightly with increasing temperature. Combined results on (i) the sound velocity of $Fe_3P$, Fe-5wt%P liquids at high pressures (Fig. 1) (ii) the phase diagram of $Fe_3P$, Fe-5wt%P (Fig. 3) and (iii) the density measurements of $Fe_3P$ (Fig. 2), provide tight constraints on the equation of state and thermodynamic properties for Fe-P liquids. The sound velocity data and EoS can be used to calculate other thermodynamic properties such as the Grüneisen parameter and the adiabatic temperature gradient under planetary core conditions. Such properties are important to understanding the thermal evolution of planetary cores such as the core of Mercury.

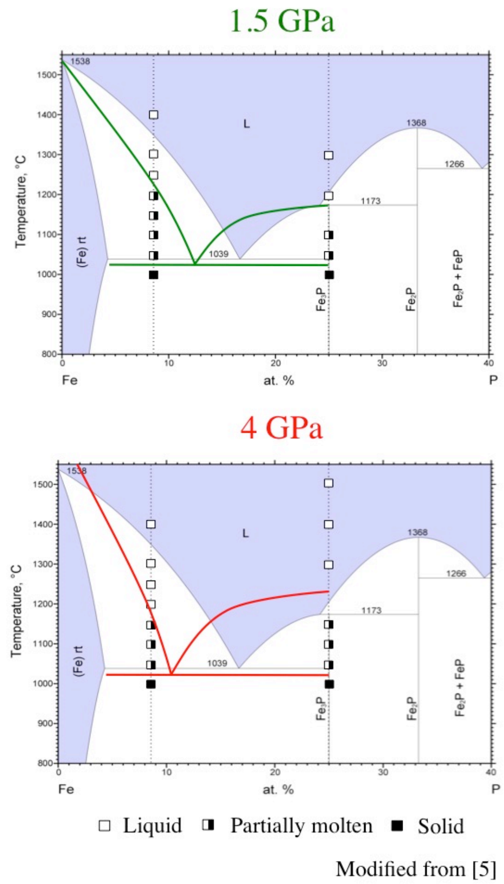


Fig. 3. Phase diagrams for Fe-P

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