PENNSTATE

Process Control for Food Freezing

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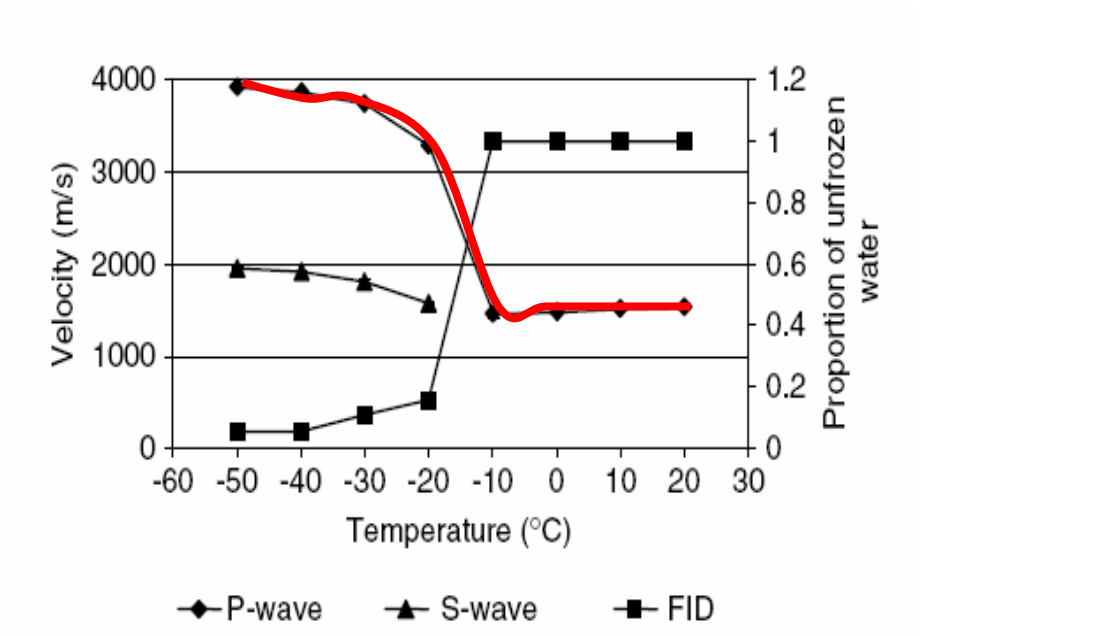
CRYO-QUICK
AIR PRODUCTS
NITROGEN

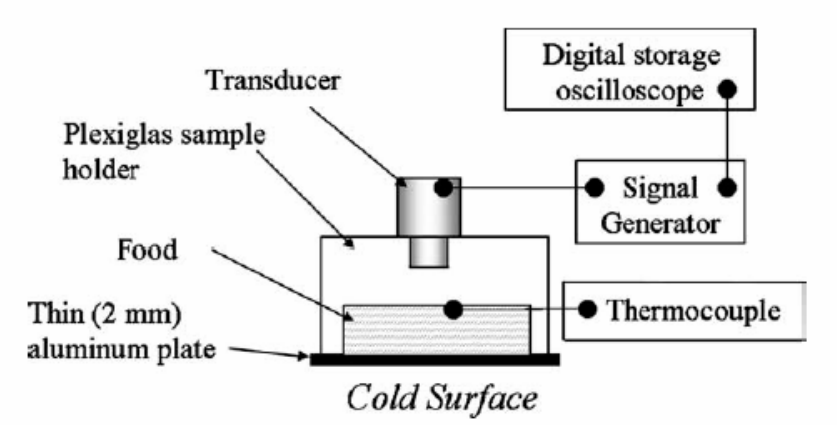
Freezing of Orange Juice

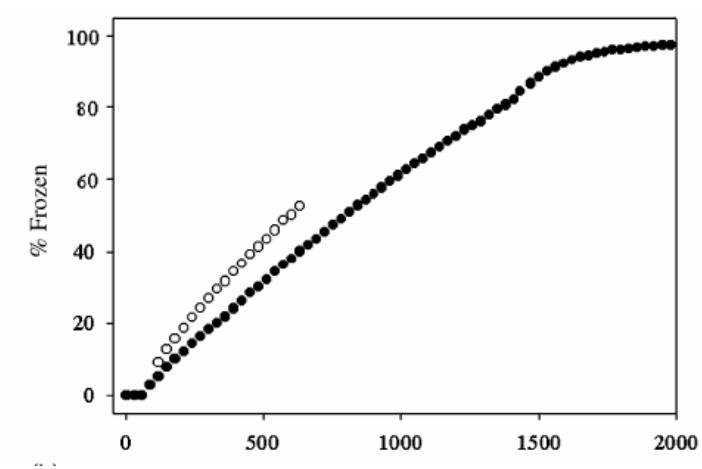


Comparison of ultrasonic velocities with the proportion of unfrozen water in orange juice (10% solids content) over temperature.

Lee, Pyrak-Nolte, Cornillon & Campanella, 2004

Monitoring of Freezing





Experimental setup and fraction of water frozen in the sample as a function of time. Two methods were used (●: location of the position of the ice front, ○: overall time-of-flight).

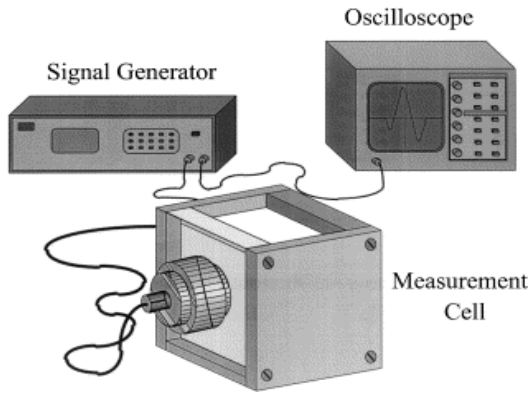
Sigfusson, Ziegler & Coupland, 2004

Primary Research Questions

- For an equilibrium ice-solution mixture how is %ice related to ultrasonic properties?
- How does ice structure affect the results?
- Can these measurements be made online?

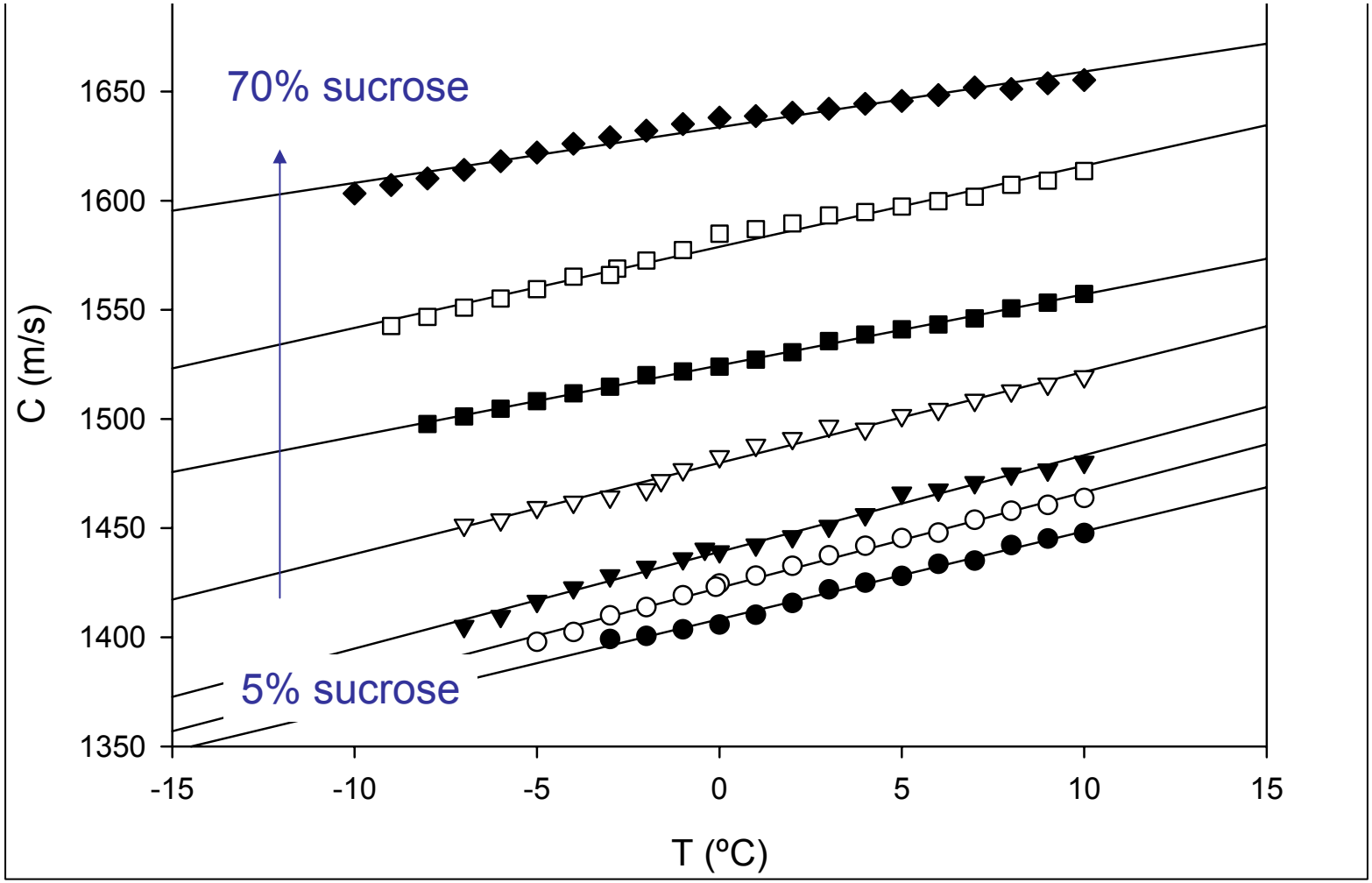
Ultrasonic Measurements

- Pulse-echo measurement system.
- At all times, the sample cuvette is held in a temperature controlled water-bath (0.01°C precision)
- Broadband L-wave transducers: 2.25 MHz at all times, 4 others (1, 3.5, 5, 10 MHz) for frequency dependence determination.

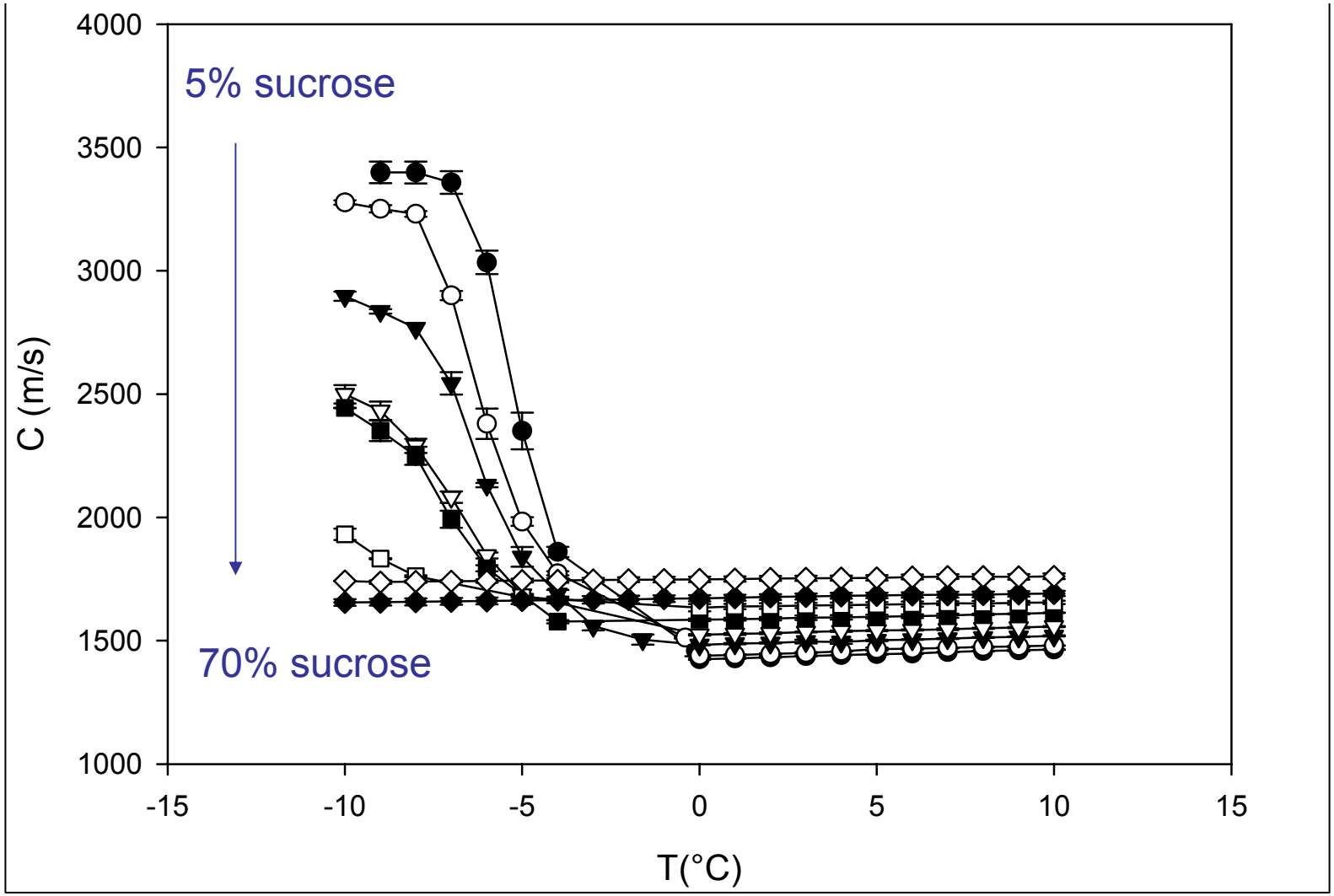


(*Figure from* Sigfusson, Decker & McClements, 2001)

Non-Freezing Sucrose



Freezing Sucrose



Sucrose Phase Diagram

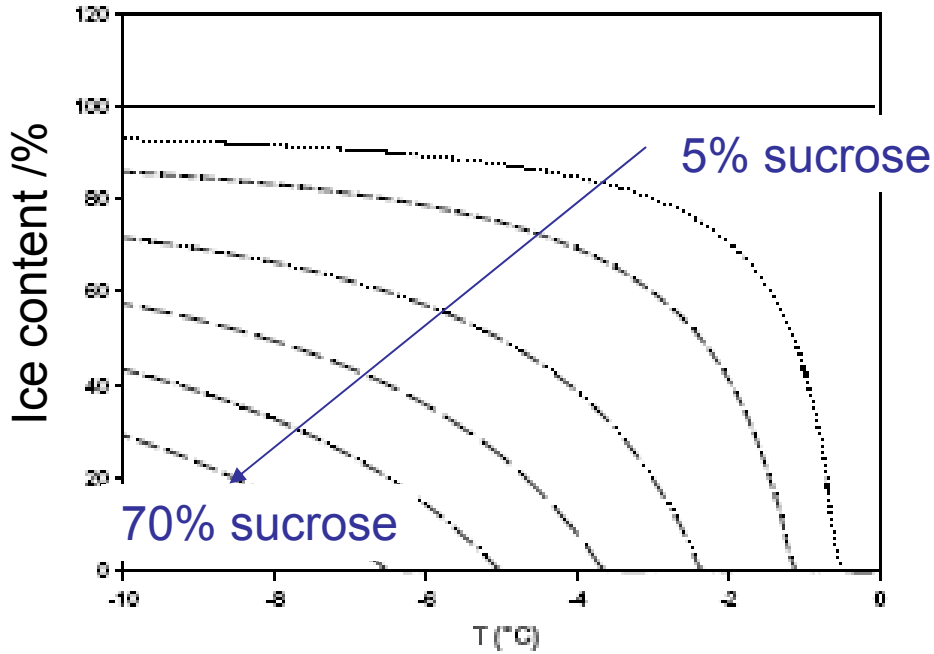
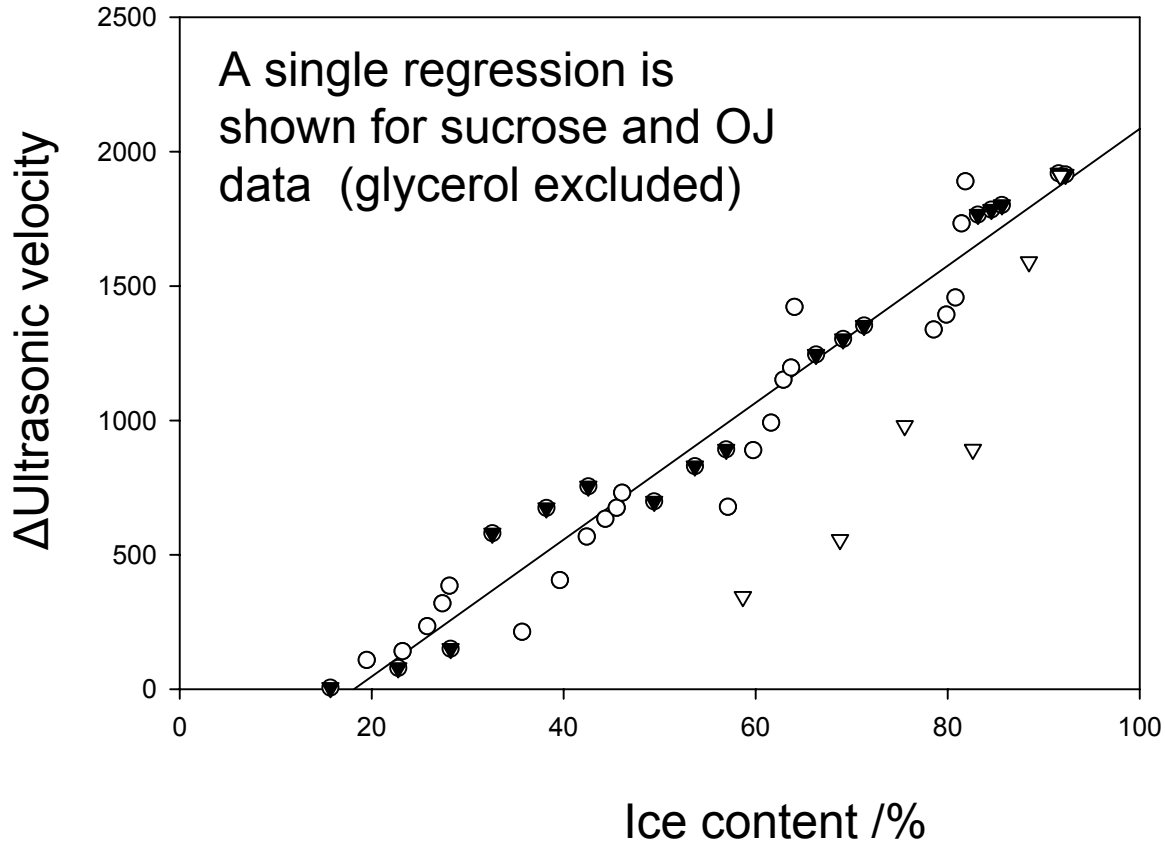


Fig. 5a. Ice content of sucrose solutions as calculated from melting point depression data (from top to bottom: pure water, 5%, 10%, 20%, 30%, 40%, and 50%).

Ultrasonic Determination of Ice Content



Effect of Ice Structure

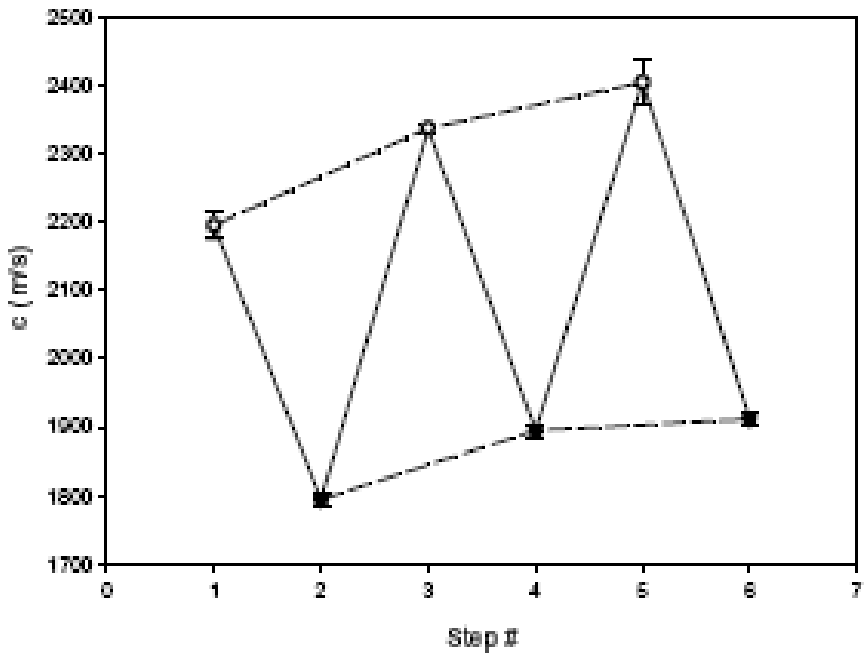


Fig. 7. Ultrasonic velocity in a frozen 20% sucrose solutions during temperature cycling odd numbered steps correspond to the measurements at −5 °C (○), and the even numbered ones to those in −3 °C (●). Solid lines connect consecutive measurements while dotted lines connect the measurements at each temperature.

Ultrasonic velocity and crystal size increase with temperature cycling

On-Line Measurement

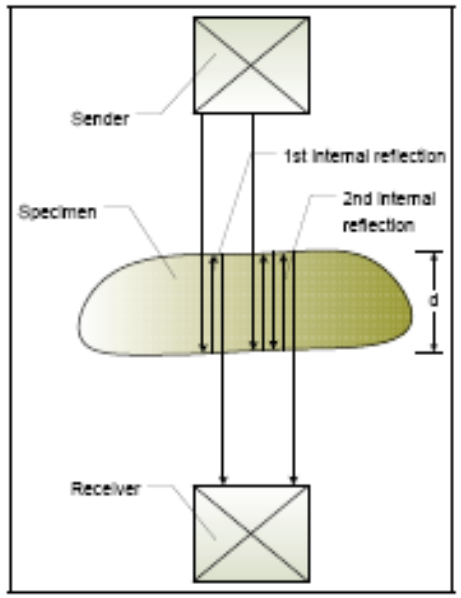
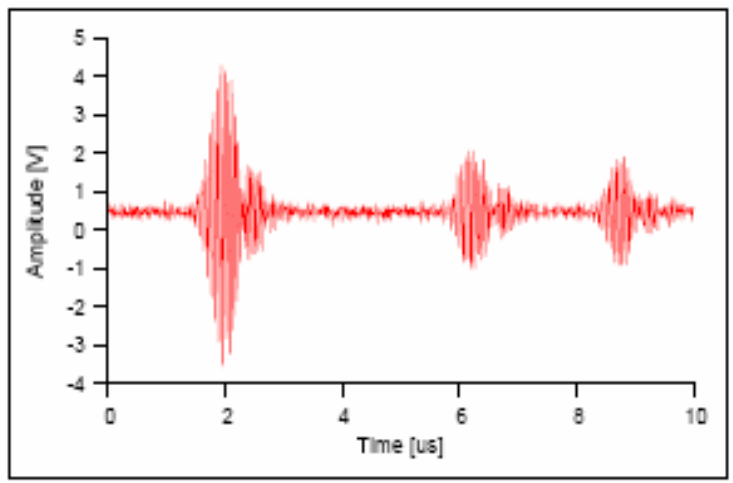


Fig. 3.2: Traveled path of internal reflections



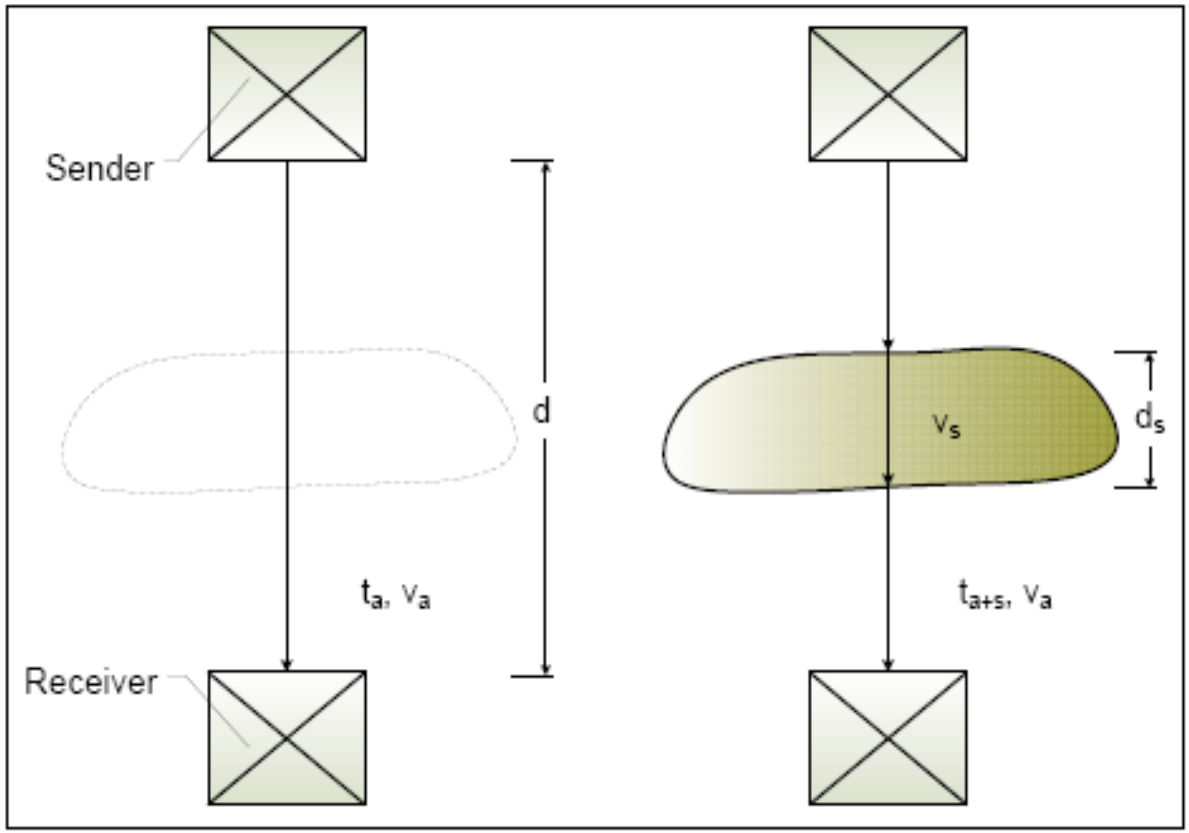


Fig. 4.2: Calculation of acoustic velocity based on main peak only

Vacuum-Packed Swordfish

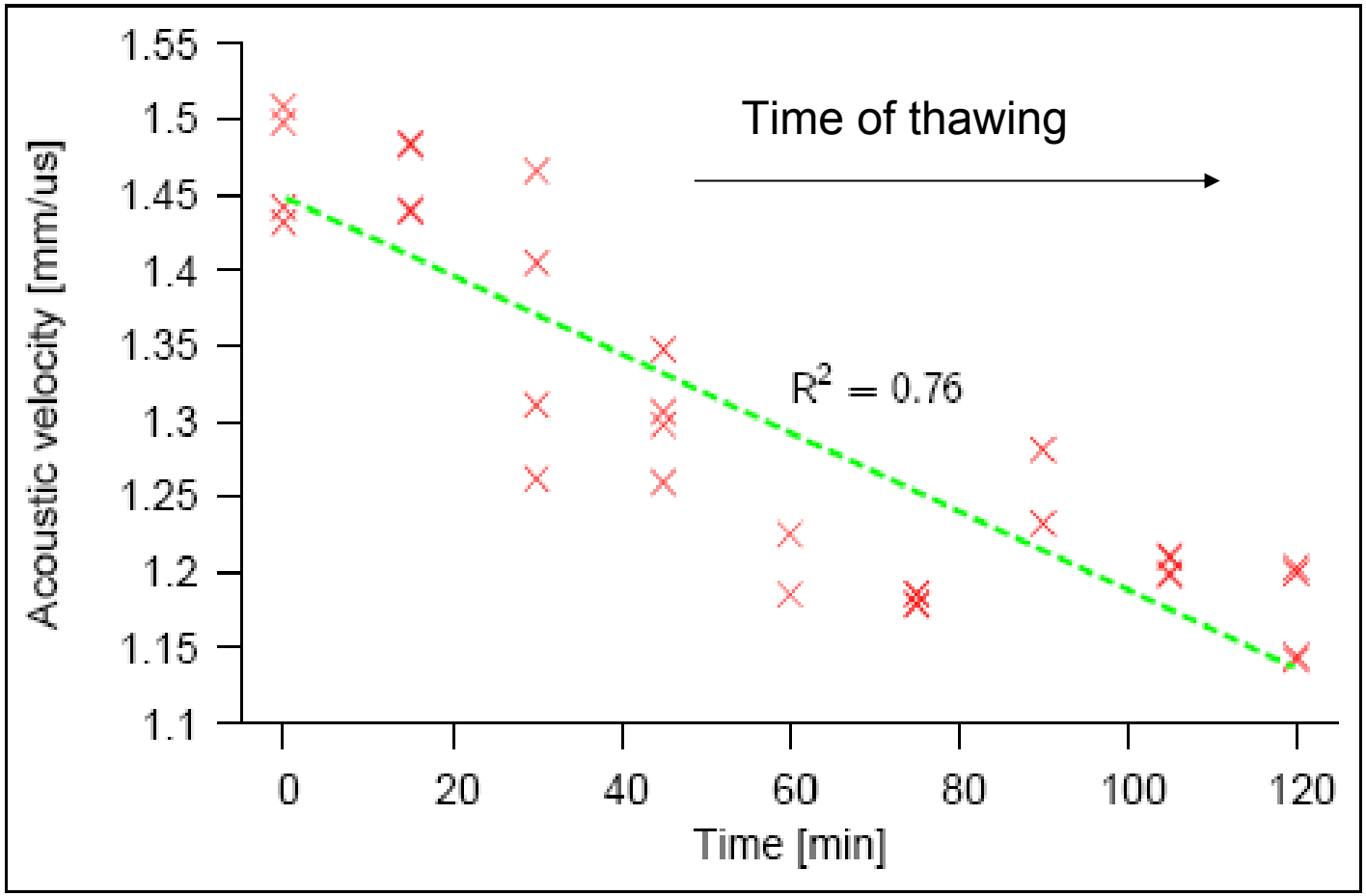


Fig. 4.3: Acoustic velocity of swordfish fillets wrapped in plastic

Hamburger patties

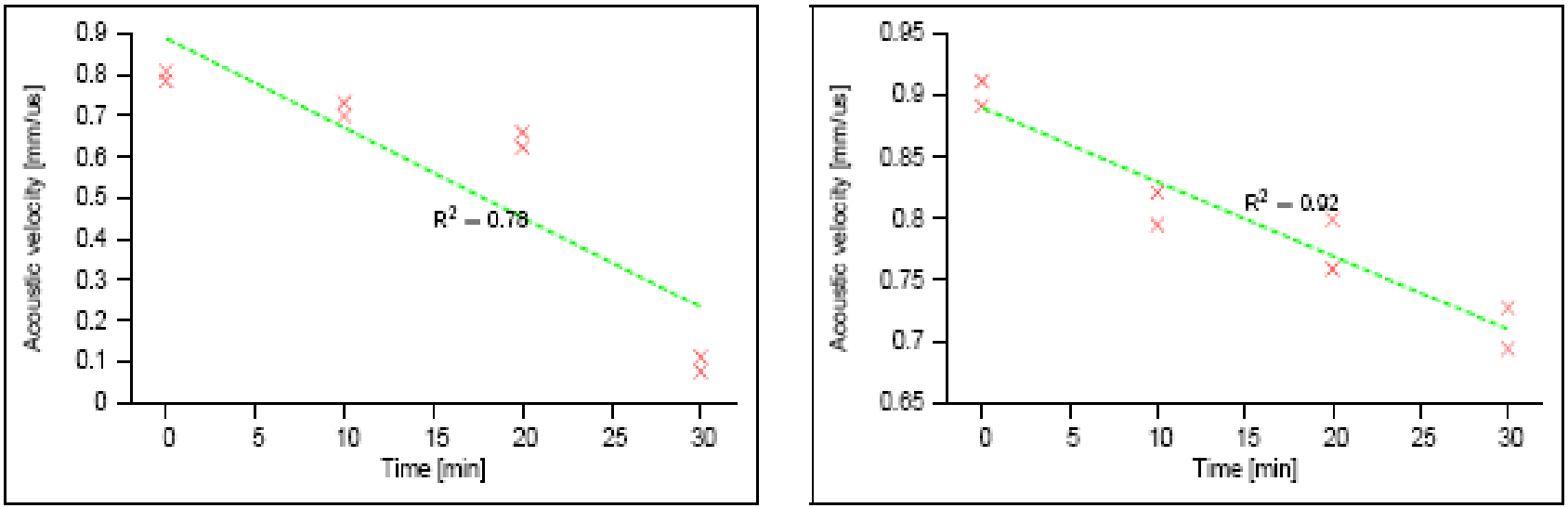


Fig. 4.8: Acoustic velocities for hamburger patties of thickness 12.9 mm and 15 mm

Ultrasonic propagation failed in

- Frozen chicken
- Frozen vegetables
- Commercial burger patties

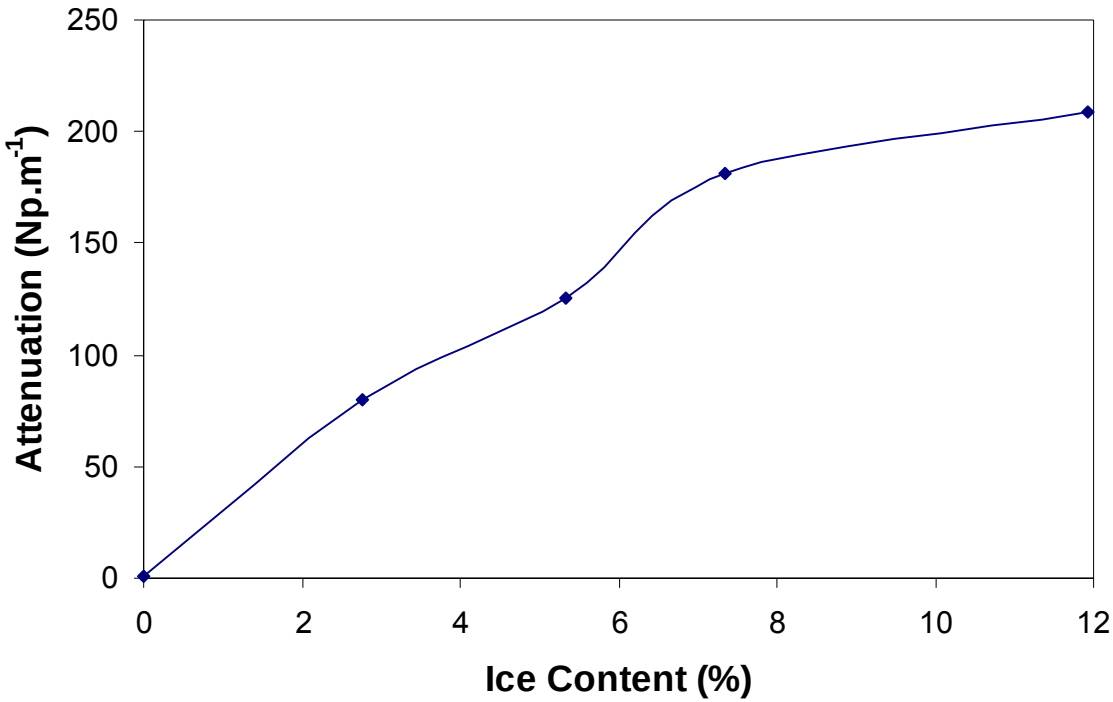
Primary Conclusions

- The change in ultrasonic velocity on freezing is proportional to ice content
- Ultrasonic velocity can be measured in a non-contact mode more suitable for on-line application

BUT

  – Frozen foods attenuate sound VERY strongly making all measurements challenging

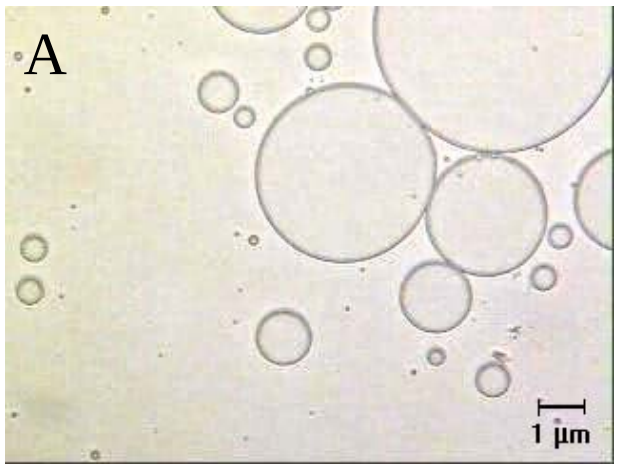
Secondary Research Question

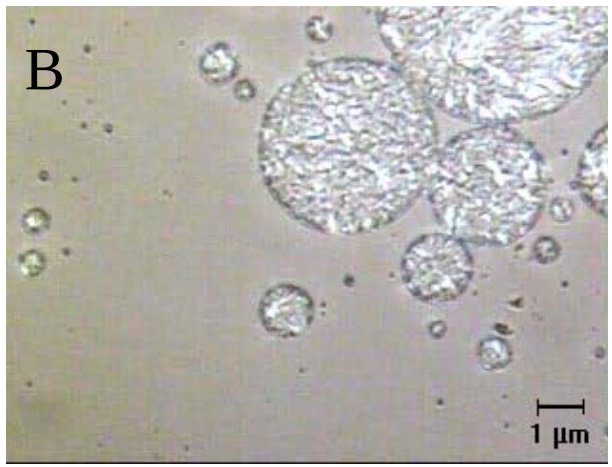


- Why do partly crystalline systems attenuate so strongly?

Emulsions as a Model System for Crystallization and Melting

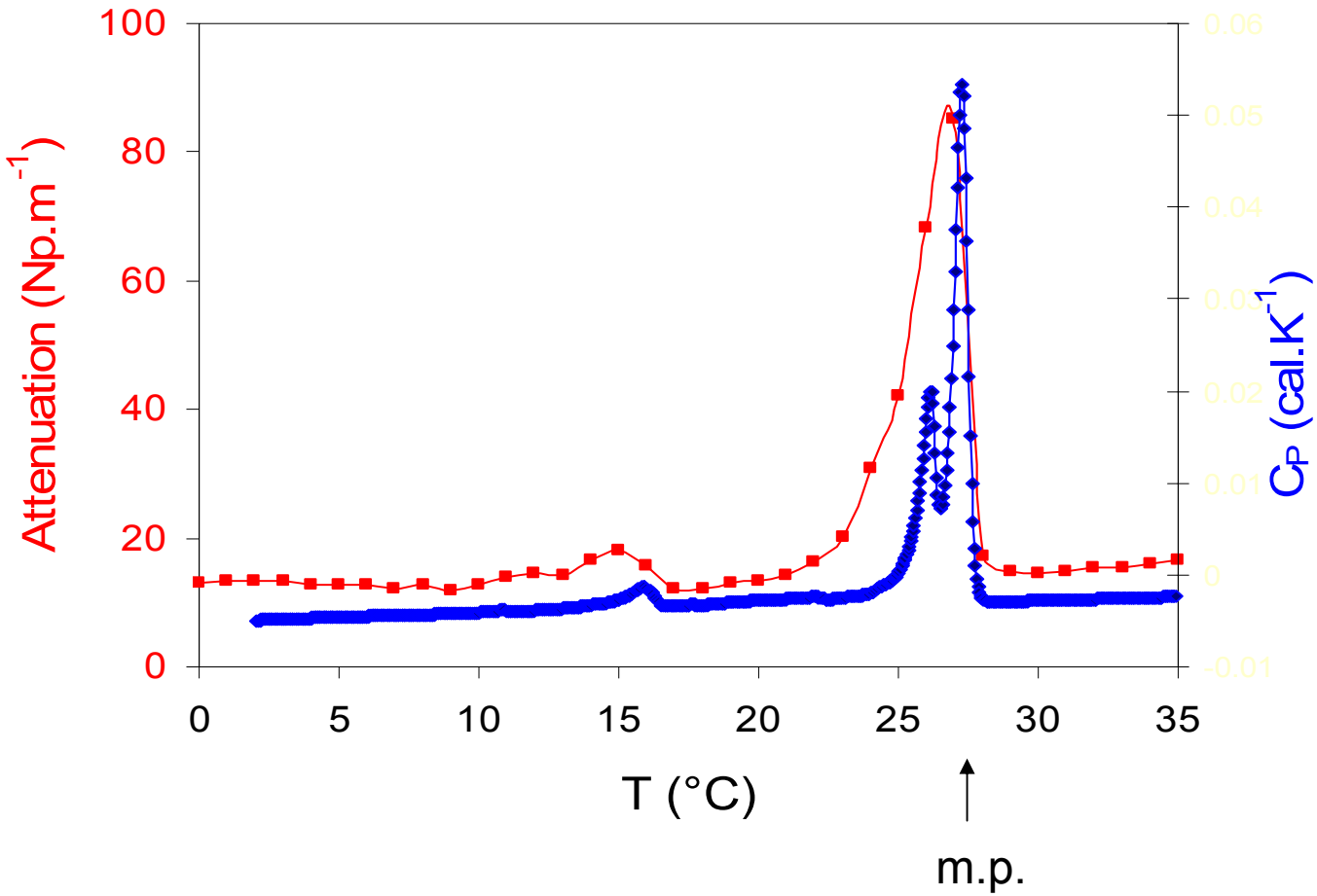
cool





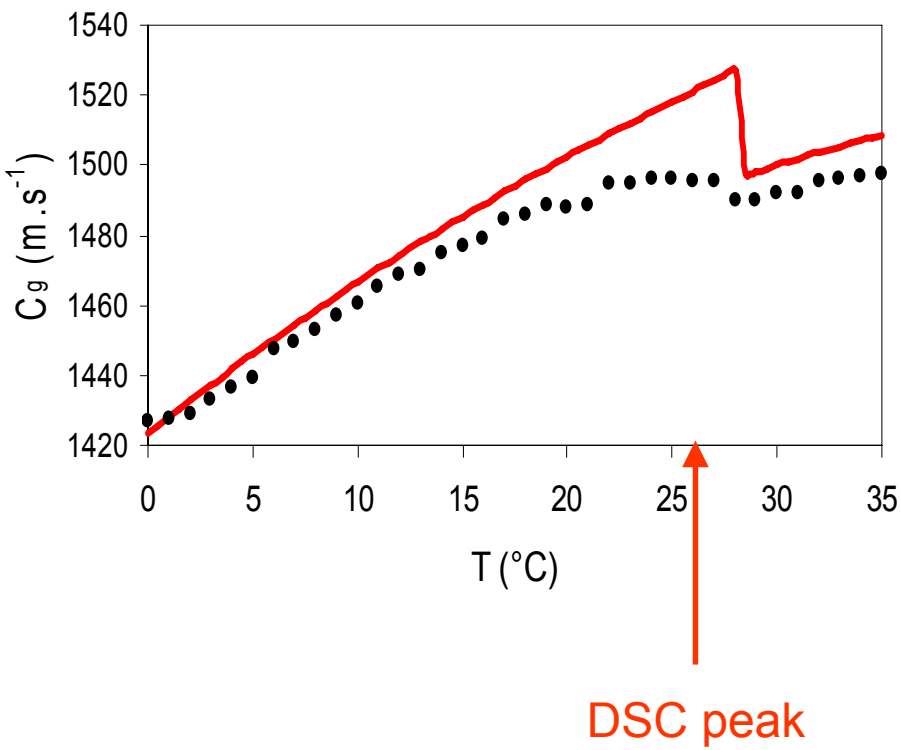
heat

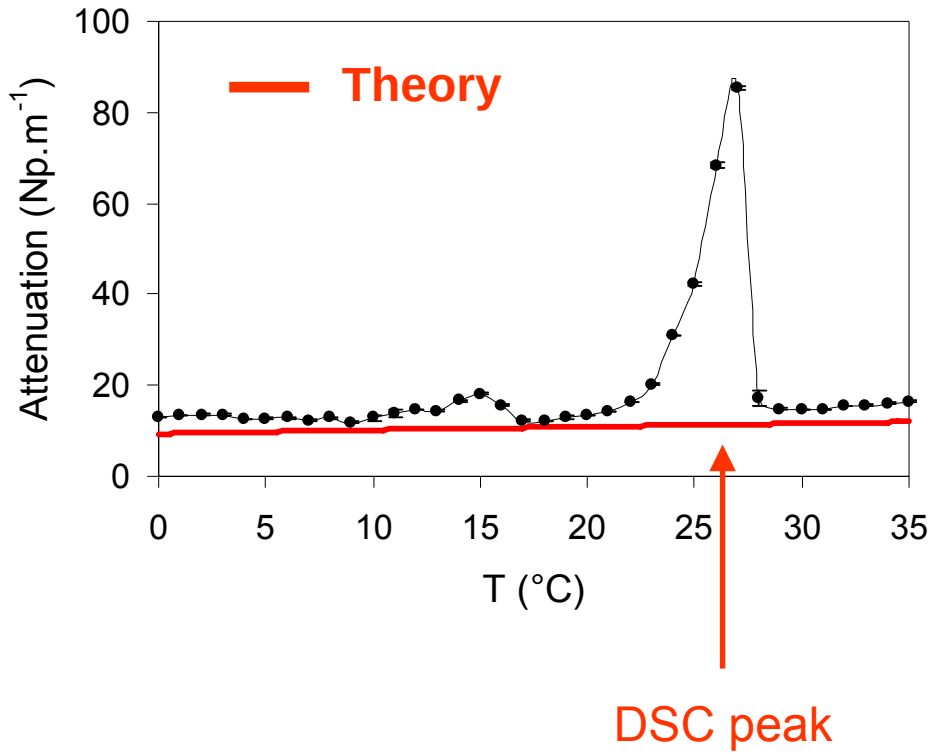
Melting: Crystalline Fat Droplets



Heating a C_{18} emulsion (d_{32}=0.45 μm) stabilized by 1% Tween 20

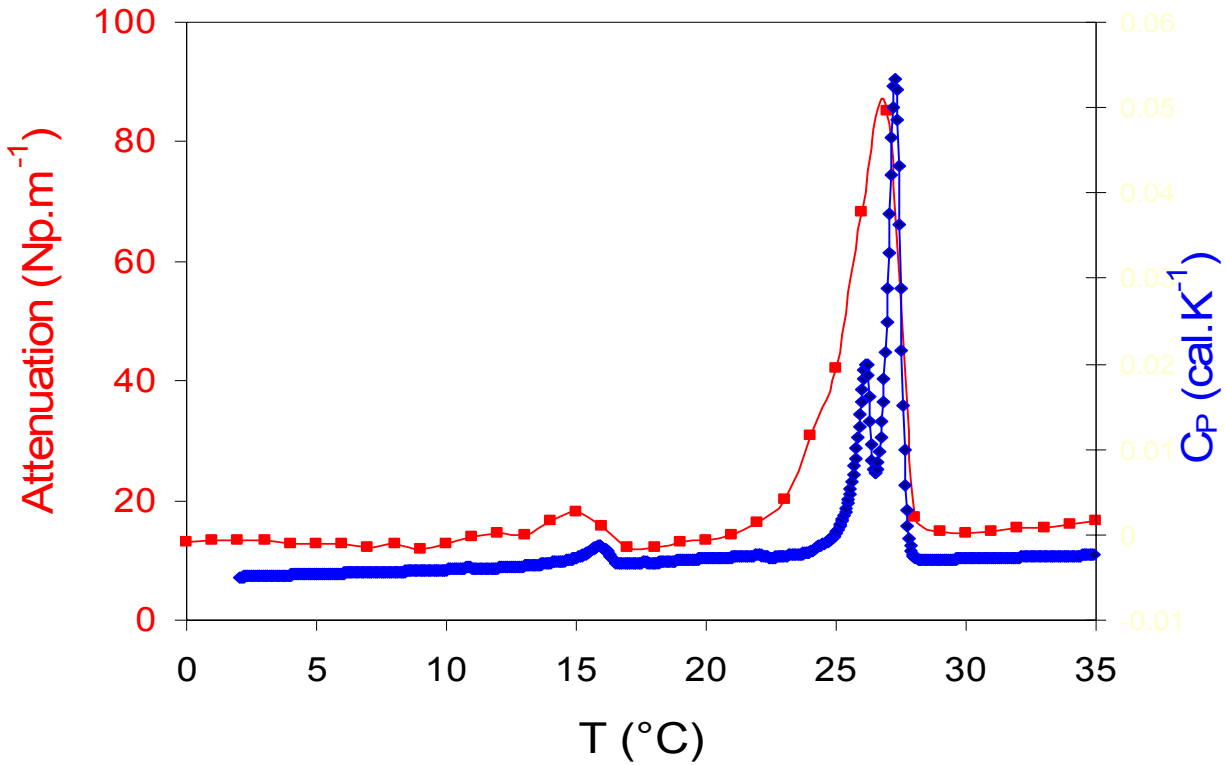
Melting of C_{18} Emulsions: Ultrasonics



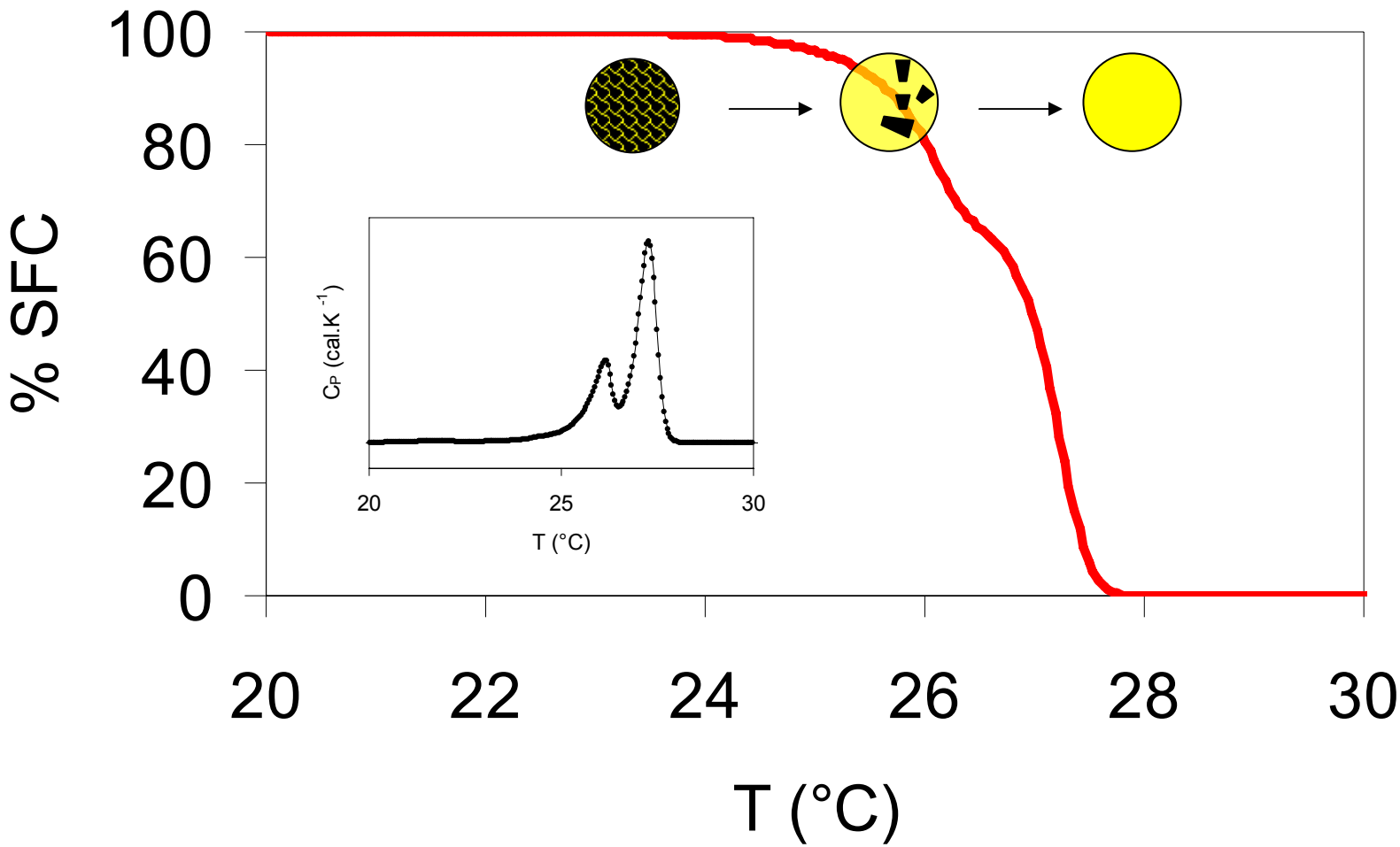


Theoretical prediction=f (density, specific heat, thermal conductivity, thermal expansion coefficient and ultrasonic properties) of the component phases.

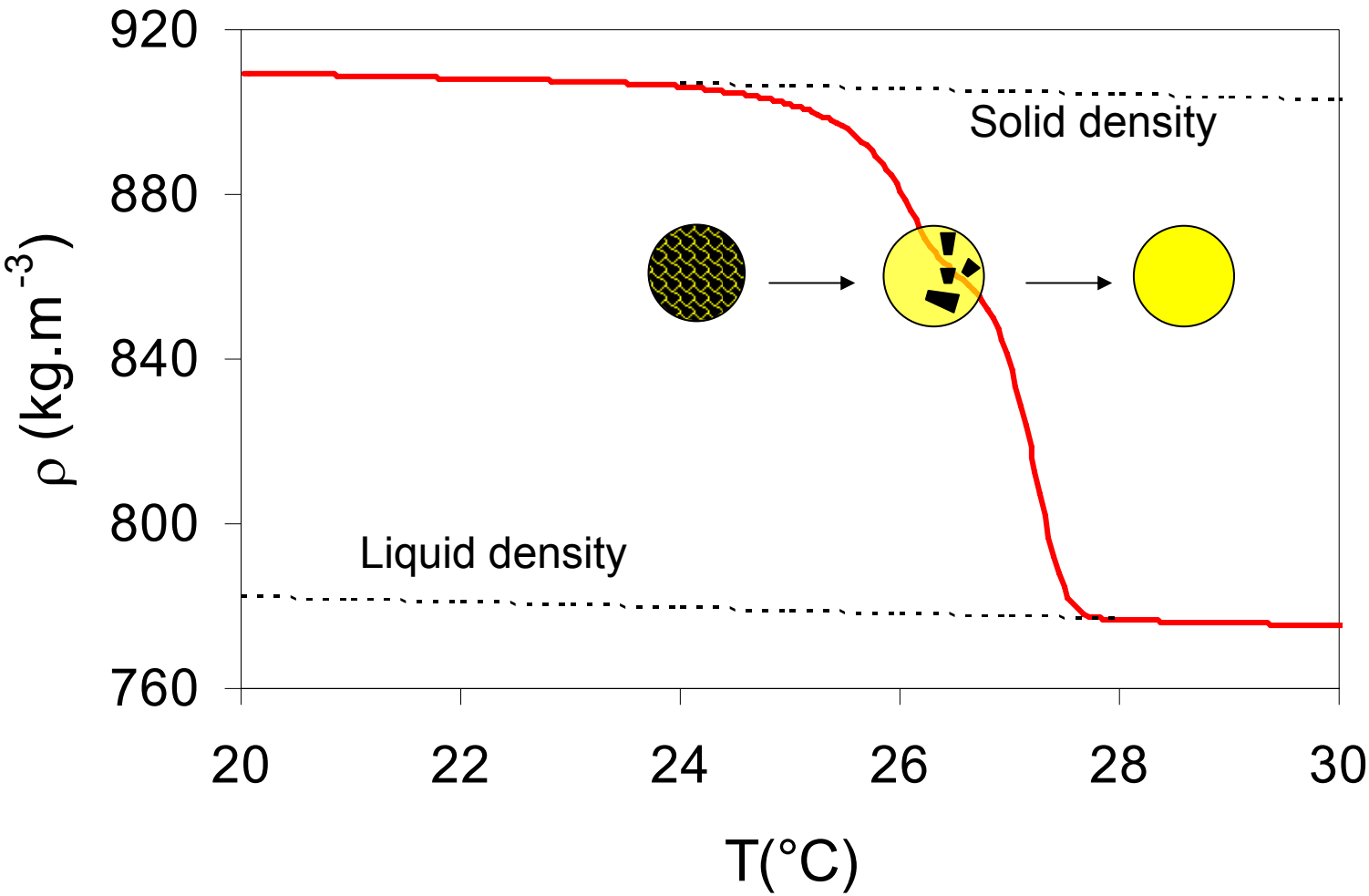
Heating of 3% C_{18} emulsion (d_{32}=0.45 μm) stabilized by 1% Tween 20


100
80
60
40
20
0
Attenuation (Np.m-1)
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
CP (cal.K-1)
0
5
10
15
20
25
30
35
T (°C)

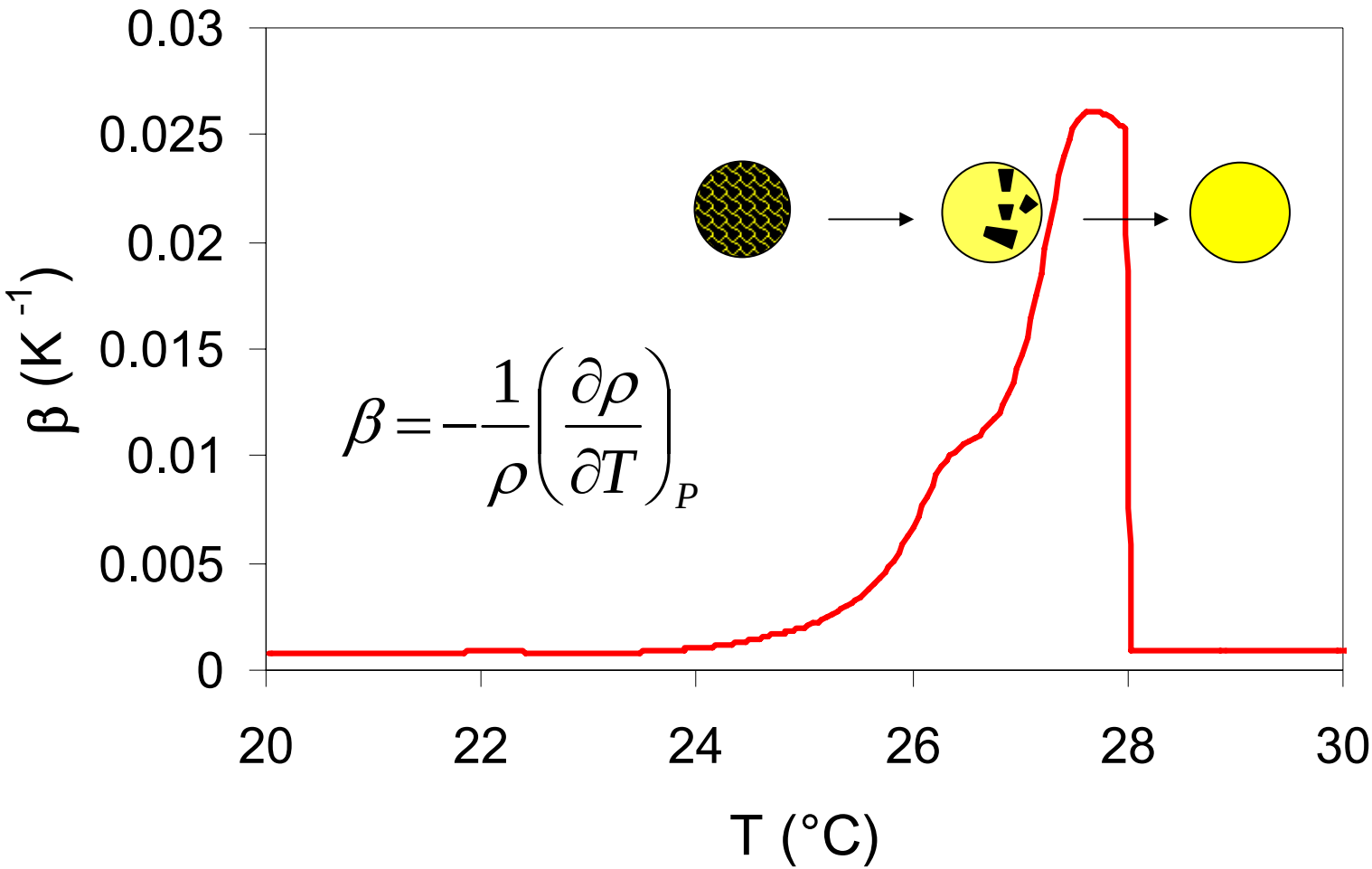
SFC during Melting



Effective Lipid Density during Melting

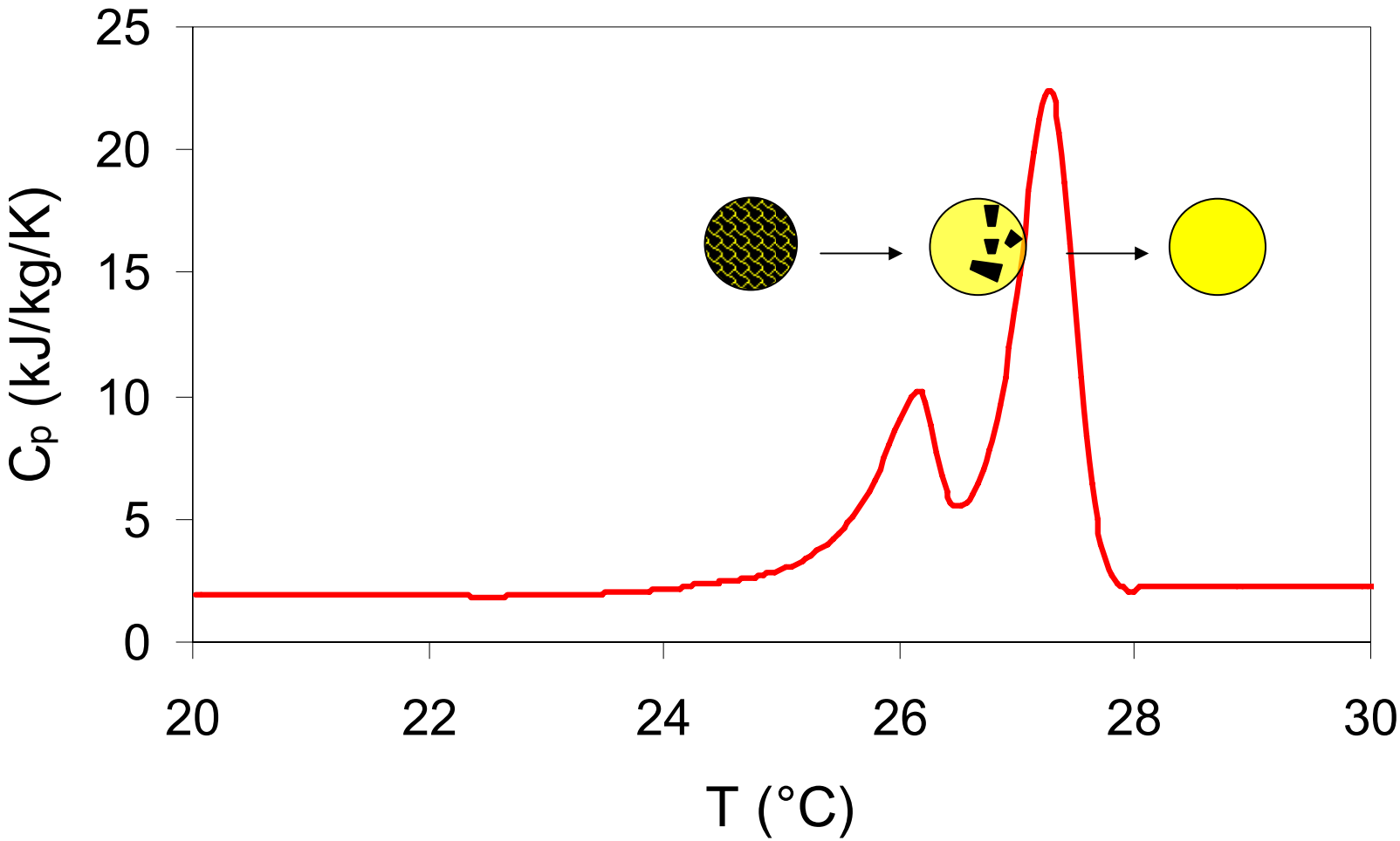


Effective Cubical Expansion Coefficient During Melting

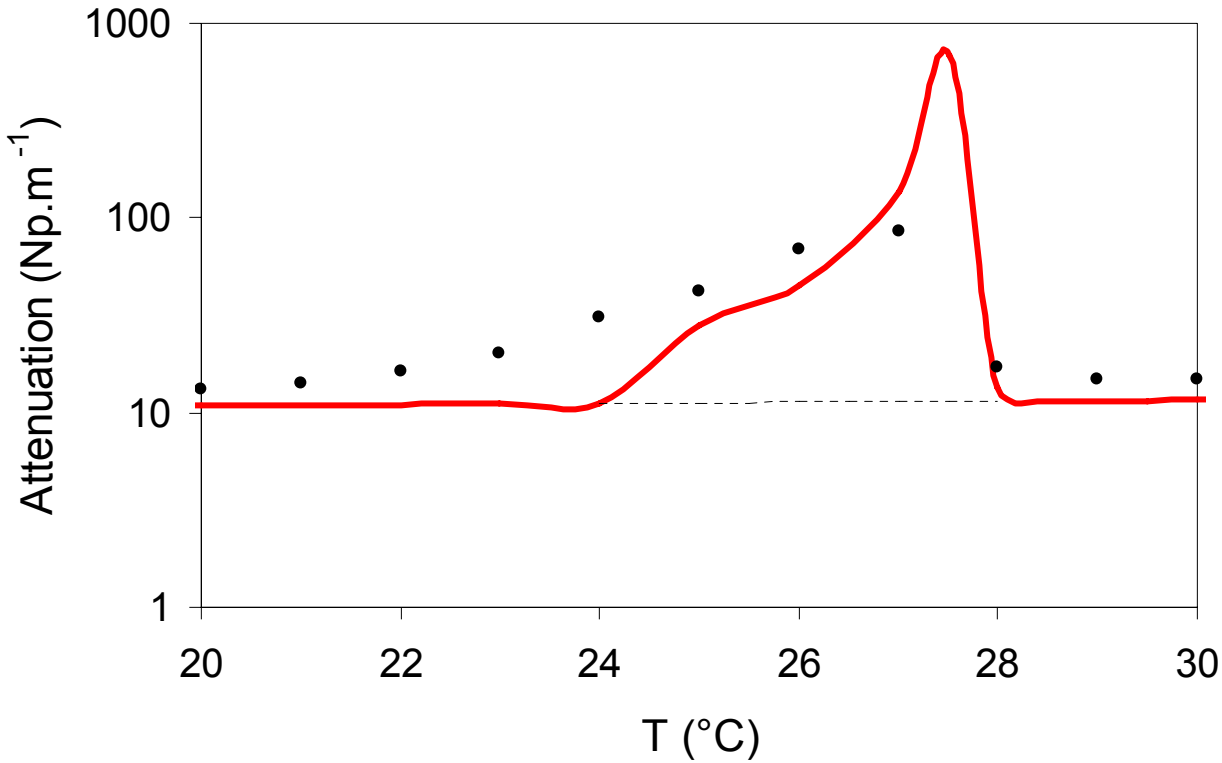


$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P$$

Effective Specific Heat during Melting



Using Effective Parameters in Scattering Theory



(line=calculation, points=measurement)

Secondary Conclusions

- The ice in a partly frozen food is in equilibrium with an unfrozen solution. The ultrasonic wave perturbs the equilibrium and significant sound energy is lost in the process.
  - *Can we use attenuation measurements to get a sense of the dynamics of the enthalpy change (e.g., in shortenings or chocolate)?*