Chapter 6 Questions

1. Estimate the maximum size (in *a* units) of fractal flocs when a suspension with volume fraction of 0.20 gels under RLCA.

2. Discuss and explain the phase behavior of a suspension of spherical particles (ϕ=0.59) when the (short range) interparticle attraction force is gradually increased from zero to large values. The system does not crystallize. How will this affect the viscosity?

3. Discuss and explain the viscosity of dilute and semi-dilute (up to the ϕ^2 term) suspensions of attractive hard spheres.

4. What is the rheological signature of a critical gel?

5. Discuss the difference between depletion and polymer bridge flocculation in creep and recovery experiments.

Chapter 6 Answers

1. For RLCA the fractal dimension D_f is approximately 2.0. Using eq. 6.5 one then finds $R_{gel}/a = 5$.

2. For hard spheres the glass phase starts at ~0.58. Hence, the present system is a glass without attraction forces (repulsive glass). When attraction forces are gradually introduced the glass line shifts to higher volume fractions and, a sample of ϕ=0.59 will cross this line entering the liquid range. At still higher attraction forces the sample should become glass-like again ("re-entry") because particles sticking together now limits their mobility (attractive driven glass). In the glass phases the low shear viscosity should diverge, with a finite zero shear viscosity in the intermediate liquid region. Hence low shear viscosity should display a minimum when gradually increasing the attractive interaction forces. Finally, note that the high shear limit should not be affected by the presence of the attractive forces.

3. In the dilute regime particles are too far apart for the attractive forces to have an effect. Hence, in this range the viscosity for attractive hard spheres is identical to that caused by hard spheres. At the ϕ^2 level interactions appear. The attractive forces bring particles closer together, which increases the hydrodynamic interaction and consequently the viscosity. There is also a viscosity effect due to a direct contribution from the attractive interparticle force. Hence, the net effect is generally a viscosity increase above that for the Brownian case. For adhesive hard spheres with weak attraction the coefficient of the ϕ^2 term is $\left(5.9+1.9/\tau_B\right)$.

4. Assuming a structure is self-similar at all length scales above a reference one, one can describe the suspension's relaxation spectrum with a power law distribution. This spectrum of relaxation times governs the moduli. When structure develops the longest relaxation time gets larger and the low frequency terminal liquid-like behavior is pushed to lower frequencies. When this becomes significantly long (relative to the observation time) a transition between solid and liquid is reached known as the critical gel. At this stage both the storage and loss moduli are both proportional to ω^n, hence describing parallel lines in a log-log plot. Deviations will appear in both the high and the low frequency limit, but at least a decade of such linear, parallel behavior is desired. In case n=0.5, both moduli are equal at the critical gel. For fractal flocs self-similarity will be limited to the length scale of the flocs and hence, the range of the power law range cannot extend to very long times or to zero frequency.

5. Depletion forces act over the range defined by the size of the depletent, which can be relatively short-ranged in comparison to the particle size. Hence, relatively small strains can move particles out of the range of attraction and the sample will flow. Upon reducing the applied force to zero, there will be little to no elastic recoil in this case. On the other hand, polymer bridges can be stretched at over a range of stress

levels, resulting in an elastic behavior. Upon releasing the stress the polymer bridges will draw back and display a substantial recoil. Note that polymer bridging forces can be significantly greater then depletion forces, such that bridging gels can have might larger elasticity and yield stresses.