effects are proportional to the number of CA molecules available, assuming there is abundant water available. (This assumption may break down in certain imaging situations, such as in molecular MRI where the CA can accumulate inside the cell.) The effectiveness of the CA on enhancing 1/T1 and 1/T2 is characterized by its relaxivities $r1$ and $r2$ for a given CA of concentration C:

$$1/T1 = 1/T1{,}0 + r1\,C.$$
$$1/T2 = 1/T2{,}0 + r2\,C.$$

[3.47]

Here $1/T1{,}0$ and $1/T2{,}0$ denote the relaxation rates without CA presence. Because 1/T1 (spin interaction at Larmor frequency) is small (long T1) and 1/T2 (spin interaction at DC) is large (short T2) in most tissues (Eqs.3.6&7), the percent change in T1 relaxation is much greater than it is in T2 relaxation. Accordingly, MRI CAs are typically used to enhance T1 weighted imaging.

Example 1. **Chemical exchange transverse magnetization among difference frequencies and relaxivity**. The paramagnetic CA molecule generates a magnetic field in its surrounding, which is simply modeled as a region with off frequency $\Delta\omega$. Water exchange between this and other regions (transverse magnetization m' and m) at a rate k. Eq.3.13a can be extended to include this exchange effect ($r = 1/T2{,}0$):
$dm/dt = -(r+k)m + km', dm'/dt = -(r+k+i\Delta\omega)m' + km.$
This 1st order linear differential equations with $(m, m')_{t=0} = m_0(1{,}0)$ is solved as:
$m(t) = m_0(e^{-2kt} + e^{-i\frac{\Delta\omega}{2}t-\left(r+\frac{(\Delta\omega)^2}{8k}\right)t})/2.$
The first term decays rapidly ($k >> r$). The second term leads to ($Ck = 1/\tau$, with τ the time constant for water getting into the $\Delta\omega$ region):
$1/T2 = 1/T2{,}0 + C\,\tau(\Delta\omega)^2/8$, or $r2 = \tau(\Delta\omega)^2/8$ in Eq.3.47

Example 2. When a contrast agent binds with the large protein albumin in the blood plasma, the correlation time increases. As such, the relaxivities of contrast agents increase with albumin binding. Interestingly, the relaxivities of the Gd-albumin complexes may peak at a certain field strength, otherwise, contrast agent relaxivity tends to decrease with MRI field strength (Fig.3.23).

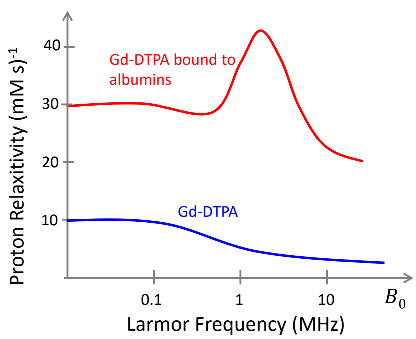

Fig.3.23. Contrast agent relaxivity dependence on field strength.