facilitate determination of the stress in an actual pipe. The following example illustrates the computation of stress.

Example: What is the force set up by a 1 in. schedule 40 steel pipe if the thermal expansion from a 100 deg temperature increase is fully constrained?

Answer: From Table 1, determine that for a 1″ schedule 40 steel pipe, the metal area = 0.494 sq. ins. Then, from Table 20, aE = 195 psi, and from Equation 3

$$F = 195 \times 0.494 \times 100$$
$$= 9630 \text{ lbs.}$$

It is interesting to note that length does not enter into the determination of the constraining force. This is so because the stress is a *unit length* function and so is the expansion; therefore, they cancel each other. In other words, if a weight stretches a 10-foot wire 0.10 in., then that *same* weight would stretch a 100 foot wire one inch. In both cases the elongation was 1 part in 1200. The realization that thermal *stress* is independent of length is important, but often overlooked. Nonetheless,

TABLE 20. PHYSICAL PROPERTIES FOR DETERMINING THERMAL STRESS
(*Temperatures between 32 and 400 F*)

	Steel	Wrought Iron	Cast Iron	Brass or Bronze	Copper	Aluminum
Coefficient of Linear Expansion, $a \times 10^6$	6.5	6.8	5.95	9.85	9.3	13.5
Modulus of Elasticity, E, psi $\times 10^{-6}$	30	28	12	14	16	10
Product of aE, psi	195	190	71.4	138	149	135

Example: The coefficient of expansion for steel = 0.0000065 in./in. and the modulus of elasticity = 30,000,000 psi. Therefore aE = 195 psi.

that concept explains the feasibility of utilizing the inherent flexibility of the pipe to take care of expansion.

Regardless of the length of pipe between anchors, it is possible to take care of the expansion by putting the force of expansion into the pipe as internal stress.

If the pipe is not straight, then the force of expansion will cause a bending moment. The pipe will then be under a combined stress. The stresses will be longitudinal and transverse, and to a small extent radial. All of these stresses tend to fracture the pipe, and therefore must be added to make up what is called *allowable combined stress*. The *Code for Pressure Piping, ASA* B31.1, published by the *ASME*, sets up very definite limits for the allowable combined stresses for various pipe materials. For temperatures below 400 F and for piping that is for neither district heating nor power, any standard pipe material may be used. For high temperature or high pressure work, some text on expansion and flexibility should be consulted. It is beyond the scope of this chapter to develop the theory of expansion caused by high temperatures.

For the simpler problems encountered for temperatures 400 F and less, which the heating engineer is more apt to encounter, there are four methods of allowing for expansion.

The first method is to use *packless* expansion joints. These joints include types of bellows expansion joints, rubber, corrugated copper and other metals.

Rubber type joints are generally used in vacuum or low pressure steam lines. Maximum temperature is generally 180 F. If oil is present in the line, rubber type joints will be attacked. Travel of these joints is up to 1 inch. The travel to be expected can be calculated by using Equation 2.

The second type of expansion joint is called a *slip* joint. This joint allows for expansion by a sliding of a female member over a male member. The joint is kept tight by means of packing. The packing determines the limit of the temperature to which the joint may be subjected. The main disadvantage to this joint is that it must be continually inspected for a deterioration of the packing. By using double slip joints, the travel may go to several feet, but generally a single joint allows about a foot of expansion. It is common practice to use slip joints up to 250 psi.

The most common method of allowing for expansion in heating systems is to use the swivel joint. This is the third method. The swivel joint was first used with screwed fittings, but it is also used now with welded fittings. With welded elbows, the swivel introduces torsional stress in the elbow and in the swing piece. This type of joint is adequate for taking up the

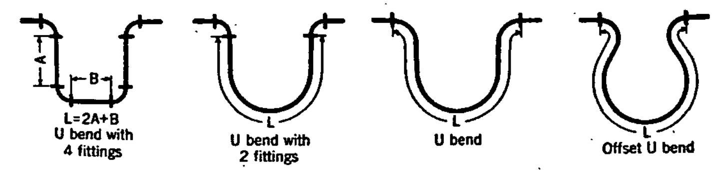

FIG. 3. MEASUREMENT OF L ON VARIOUS PIPE BENDS

expansion in a header, and preventing fracture of the riser or heating element.

The fourth method is to allow the flexibility of the pipe to absorb the stress of expansion. A technique used to reduce the stress in the expanded pipe is to *cold spring* it before hooking it up. Cold springing can be used to absorb about one-half the stress. The technique is to install the pipe with an opposite stress. For example, if the pipe were to have a compression of 2000 psi, then the pipe would be installed with 1000 psi of tension. For refrigeration, the pipe would be cold sprung in compression.

For conditions not requiring rigorous analysis, it is permissible to use expansion bends designed by means of Equation 4

$$L = 6.16\sqrt{D\Delta} \quad (4)$$

where

L = length of pipe, feet.
D = O. D. of pipe, inches.
Δ = deformation, inches (see Equation 2) fiber stress $\leq$ 16,000 pounds per square inch.

Equation 4 can be used for bends with two fittings, regular U-bend, and offset U-bend, as shown in Fig. 3. It gives the length of pipe, L, that