Evidence against the Folate-mediated Formylation of Formyl-accepting Methionyl Transfer Ribonucleic Acid in Streptococcus faecalis R*

(Received for publication, May 25, 1970)

CHARLES E. SAMUEL,† LINDA D’ARI, AND JESSE C. RABINOWITZ
From the Department of Biochemistry, University of California, Berkeley, California 94720

SUMMARY

The formylation of formyl-accepting methionyl transfer ribonucleic acid (tRNA<sub>Met</sub>) was investigated in Streptococcus faecalis R, an organism incapable of synthesizing folic acid but whose growth does not require the vitamin under defined conditions of culture. These studies were carried out because it was not clear how an organism with no folate could initiate protein biosynthesis. Growth of S. faecalis R on media free of folate but containing serine, methionine, thymine, adenine, and guanine was not affected by the presence of the folate antagonists, trimethoprim and aminopterin. However, growth of the organism on media lacking thymine and dependent upon the presence of either folic acid or 5-formyltetrahydrofolate was severely inhibited by the analogues. It was demonstrated that extracts prepared from S. faecalis R grown on a synthetic medium containing folic acid catalyzed the formylation of methionyl-
tRNA<sub>Met</sub>, whereas extracts prepared from cells of this organism grown on a medium free of folate but containing serine, methionine, thymine, adenine, and guanine catalyzed the formylation of methionyl-
tRNA<sub>Met</sub> only when 10-formyltetrahydrofolate but not when formate was used as the source of the formyl group. Extracts of these folate-free cells catalyzed the formylation of methionyl-
tRNA<sub>Met</sub> by formate if tetrahydrofolate was added as the formyl donor, whereas extracts of the formylated cells catalyzed the formylation of methionyl-
tRNA<sub>Met</sub> by formate if 10-formyltetrahydrofolate was added as the formyl donor, and the formyl donor, 10-formyltetrahydrofolate. The role of fMet-tRNA<sub>Met</sub> as initiator of protein biosynthesis has also been indicated in Bacillus subtilis (16, 17), baker’s yeast (18), Bacillus stearothermophilus and Micrococcus lysodeikticus (19), Pseudomonas aeruginosa (19, 20), Euglena gracilis chloroplasts (21), Phaseolus vulgaris chloroplasts (22), yeast mitochondria and rat liver mitochondria (23) and mitochondria of HeLa cells (24). Furthermore, it has recently been proposed that polypeptide chain initiation involving the use of fMet-tRNA<sub>Met</sub> occurs in all prokaryotic cells, chloroplasts, and mitochondria possessing 70 S type ribosomes via a mechanism similar to that shown in E. coli.

In contrast to E. coli, Streptococcus faecalis R, a gram-positive facultative anaerobe possessing 70 S type ribosomes (26) and referred to as S. lactis R prior to reclassification in 1944 (27), is not capable of synthesizing folic acid (28-30). Although this organism is commonly used in the microbiological assay of folate compounds (19), it has been reported that this requirement may be entirely replaced by addition of serine, methionine, thymine, and a purine base, adenine or guanine, to the growth medium (31-33). It therefore occurred to us that initiation of the protein biosynthesis in S. faecalis R grown in the absence of folic acid but whose growth does not require the vitamin under defined conditions of culture.
folic acid, but in the presence of the supplements mentioned above, might occur by a mechanism different from that now accepted for other prokaryotic organisms. This investigation reports our results concerning the formyl donor dependence of the formylation in vitro of |Met-tRNA \textsubscript{fMet} catalyzed by enzymes present in the S-100 supernatant fractions prepared from \textit{S. faecalis} \textit{R} grown in medium containing folic acid, or in a medium free of added folate but containing serine, methionine, thymine, adenine, and guanine. The results obtained with \textit{S. faecalis} \textit{R} are compared to those obtained from parallel control experiments with \textit{E. coli} A19.

**EXPERIMENTAL PROCEDURE**

**Materials**—\textsuperscript{14}C-Labeled sodium formate (specific activity 53.5 mCi per mmole) was purchased from Schwarz BioResearch. Trimethoprim and ampicillin were obtained from Calbiochem. \textit{E. coli} B tRNA (stripped) was purchased from General Biochemicals. Bacto-folic acid assay medium was purchased from Difco. Folic acid was purchased from Sigma, and (\pm)-L-5-formyltetrahydrofolate (leucovorin, calcium salt) was kindly donated by the American Cyanamid Company. AlaA-A-305 was obtained from Alcon. A stock culture of \textit{S. faecalis} \textit{R} was kindly provided by Dr. B. Guirard (Department of Biochemistry, University of California, Berkeley, California) and a culture of \textit{E. coli} mutant RNase \textit{T} \textsubscript{4} was prepared by Dr. H. Franckel-Conrat (Department of Molecular Biology and Virus Laboratory, University of California, Berkeley, California).

**Preparation of S-100 Supernatant Fraction**—A modification of the method described by Blakley (35) was used to prepare (\pm)-L-tetrahydrofolate. After reduction, the material was purified on diethylaminoethylcellulose with 0.2 M Tris-chloride, pH 7.0, containing 0.5 M 2-mercaptoethanol as the eluting buffer.

**Preparation of 10-[\textsuperscript{14}C]Formyltetrahydrofolate**—A modification of the method described by Blakley (35) was used to prepare (\pm)-L-tetrahydrofolate. After reduction, the material was purified on diethylaminoethylcellulose with 0.2 M Tris-chloride, pH 7.0, containing 0.5 M 2-mercaptoethanol as the eluting buffer.

**Preparation of 10-[\textsuperscript{14}C]Formyltetrahydrofolate**—A modification of the method described by Blakley (35) was used to prepare (\pm)-L-tetrahydrofolate. After reduction, the material was purified on diethylaminoethylcellulose with 0.2 M Tris-chloride, pH 7.0, containing 0.5 M 2-mercaptoethanol as the eluting buffer.

**Growth of Cells—\textit{S. faecalis} \textit{R} (ATCC 8043)** was grown in Bacto-folic acid assay medium (38) supplemented with either folic acid, 0.001 mg per ml (final concentration), or L-serine, 0.50 mg per ml; L-methionine, 0.50 mg per ml; thymine, 0.05 mg per ml; adenine, 0.01 mg per ml; and guanine, 0.01 mg per ml. The \textit{S. faecalis} \textit{R} inoculum culture used in growth experiments was prepared by a series of four transfers on the Bacto-folic acid assay medium supplemented with L-serine, L-methionine, thymine, guanine, and adenine. The inoculum was prepared from cells transferred four times on this medium. They were then collected by centrifugation and suspended in an equal volume of medium deficient in folic acid and thymine. A 1% inoculum of the above suspension was used. Cultures were grown for 12 hours at 37° and the absorbance at 660 nm was measured on a Bausch and Lomb Spectronic 20 in 18-mm diameter tubes. Large scale growth of \textit{S. faecalis} \textit{R} yielded 2.0 g of cells from 2.5 liters of either medium. The cells were harvested by centrifugation, washed twice with 0.9% sodium chloride, and stored at -90° for less than 1 week. \textit{E. coli} A19 was grown in medium containing the following: K\textsubscript{2}HPO\textsubscript{4} (anhydrous), 2.0 g per liter; KHPO\textsubscript{4}, 3H\textsubscript{2}O, 11.0 g per liter; (NH\textsubscript{4})\textsubscript{2}SO\textsubscript{4}, 4.0 g per liter; Casamino acids, 8.0 g per liter; MgSO\textsubscript{4}, 0.24 g per liter, FeCl\textsubscript{3}, 0.27 mg per liter; glucose, 12.0 g per liter. The cells were harvested by centrifugation, washed, and stored at -90°.

**Preparation of S-100 Supernatant Fractions—**Supernatant fractions, referred to as S-100 fractions, containing methionyl-tRNA synthetase activity, transformylase activity, and the enzymes necessary for the formation of 10-formyltetrahydrofolate were prepared by alumina grinding as described by Nirenberg (39), modified as follows. The standard buffer contained 30 mM 2-mercaptoethanol in order to help stabilize any endogenous tetrahydrofolate present. After centrifugation at 30,000 \texttimes g, the supernatant solution was centrifuged at 105,000 \texttimes g for 120 min. A portion of the upper four-fifths of the resulting S-100 solution was then dialyzed 8 hours against 120 volumes of standard buffer with one change of the dialyzing medium. The dialyzed and undialyzed S-100 fractions were then frozen quickly, stored at -90°, and used within 2 weeks.

**Protein Determinations—**Protein concentrations were determined by a modification of the phenol reagent method with crystalline bovine serum albumin as the reference standard. The reagents used were twice as concentrated as those described by Lowry et al. (40) and the color development was allowed to proceed for 10 min instead of 30 min.

**Assay for Transformylation—**Transformylase activity was determined using either 10-[\textsuperscript{14}C]formyltetrahydrofolate or [\textsuperscript{14}C]formate as the formyl donor by a method based on that described by Dickerman et al. (14) and Mareker and Sanger (1). The standard reaction mixture (50 \textmu l) used when 10-formyltetrahydrofolate was the formyl donor included Tris-chloride, pH 7.4, 0.10 M; magnesium chloride, 15 mM; ammonium acetate, 10 mM; 2-mercaptoethanol, 20 mM; ATP, 5 mM; L-methionine, 0.20 mM; heterogeneous \textit{E. coli} B tRNA, 100 \mu g; varying amounts of S-100 enzyme fraction; and 10-[\textsuperscript{14}C]formyltetrahydrofolate, 0.022 \textmu M. When formate was used as the source of the formyl group, the standard reaction mixture (100 \textmu l) contained the same concentrations of reaction components, with 0.126 \textmu M [\textsuperscript{14}C]formate instead of the 10-[\textsuperscript{14}C]formyltetrahydrofolate. After incubation at 37° for the amount of time indicated, the reaction was stopped by the addition of cold 10% trichloroacetic acid, mixed vigorously, and the precipitate was collected on Whatman glass fiber filters which had been prewashed with 1 mM sodium formate. The reaction tube was washed 5 times with cold 5% trichloroacetic acid and the washes were decanted onto the glass fiber filter. The filters were then counted for radioactivity in plastic scintillation vials containing 10 ml of Bray's solution in a Nuclear-Chicago Mark I liquid scintillation counter to give a standard error of counting rate of less than 0.5%. All samples were checked for quenching by the channel ratio method but no correction was required.

**RESULTS**

**Folic Acid Requirement for Growth of \textit{S. faecalis} \textit{R}—**Growth of \textit{S. faecalis} \textit{R} is dependent upon the addition of folic acid or a combination of the metabolites serine, methionine, a purine, and thymine. These metabolites are now recognized to be products
of biosynthetic reactions that require the participation of a tetrahydrofolate derivative. Since the Bacto-folic acid assay medium is a synthetic medium that contains hydrolyzed casein, adenine, guanine, and p-aminobenzoic acid, growth of S. faecalis R on this medium was found to be entirely dependent upon the addition of folic acid or thymine. The relative rates and extents of growth of the organism in the presence of optimal quantities of folic acid or thymine, and additional serine, methionine, adenine, and guanine were compared. The inoculum used was grown through four successive transfers on folic acid-free medium with supplements in order to assure the absence of any folic acid in the inoculum. The growth rate on the medium containing folic acid was somewhat faster than on the non-folate medium, with doubling times of 34 and 48 min, respectively. The yield of cells after 24 hours growth was the same for both media.

Effect of Folate Antagonists—Although the results of the experiment described above suggest very strongly that S. faecalis R can be grown in the absence of any folate when it is supplied with various products of folate-mediated reactions, we considered the possibility that the organism is capable of very limited synthesis of folate, and that the limited amount that is made is used exclusively for the transfer of formyl groups to Met-tRNA^{Met} for initiation of protein synthesis. The effect of the folate antagonists trimethoprim and aminopterin on the growth of S. faecalis R under the two conditions of culture was therefore determined. Neither trimethoprim (Fig. 1) nor aminopterin (Fig. 2) inhibited growth of S. faecalis R grown in a folate-free medium supplemented with thymine, whereas both analogues were effective inhibitors of growth in the presence of added folate or 5-formyltetrahydrofolate. Aminopterin was active as an inhibitor at much lower concentrations than was trimethoprim, and was much more effective in the presence of folate than it was in the presence of 5 formyltetrahydrofolate. These results provide additional evidence that S. faecalis R can grow at a relatively normal rate in the absence of added folic acid and that the cell does not contain any functional folic acid.

Transformation with 10-Formyltetrahydrofolate—Extracts of S. faecalis R cells grown on folic acid and grown in the absence of folic acid were examined for the presence of 10-formyltetrahydrofolate-methionyl-tRNA^{Met} transformylase essentially as described by Marcker and Sanger (1) and by Dickerman et al. (14) with minor modifications described under "Experimental Procedure." The product of the enzymic reaction resulting from the transfer of the [14C]formyl group of 10-[14C]formyltetrahydrofolate into trichloroacetic acid-precipitable counts was characterized as [14C]formyl-Met-tRNA in the following manner. Treatment of the reaction mixture of a complete system with pancreatic RNase (10 µg per ml) after incubation under standard conditions solubilized 94 to 99% of the trichloroacetic acid-precipitable counts, whereas the counts were not solubilized when the mixture was treated with Pronase (50 µg per ml) for 60 min.

![Figure 1](http://www.jbc.org/)

**Fig. 1.** Effect of trimethoprim on the growth of S. faecalis R. Conditions are described under "Experimental Procedure." The Bacto-folic acid assay medium was supplemented as follows: A (O-O), thymine, 50 ng per ml; B (□-□), (+)-L-5-formyltetrahydrofolate, 0.4 ng per ml; C (A-A), folate, 0.5 ng per ml.

![Figure 2](http://www.jbc.org/)

**Fig. 2.** Effect of aminopterin on the growth of S. faecalis R. Conditions are described under "Experimental Procedure." Bacto-folic acid assay medium was supplemented as follows: A (O-O), thymine, 50 ng per ml; B (□-□), (±)-L-5-formyltetrahydrofolate, 0.4 ng per ml; C (A-A), folate, 0.5 ng per ml.

![Figure 3](http://www.jbc.org/)

**Fig. 3.** Kinetics of fMet-tRNA formation catalyzed by S-100 prepared from S. faecalis R grown in a medium containing folic acid. The standard incubation mixture was used as described under "Experimental Procedure." A (O-O), 10-[14C]formyltetrahydrofolate as the formyl donor; B (□-□), standard assay with 10-[14C]formyltetrahydrofolate except also contained 0.92 mM [14C]formate; C (A-A), standard assay with 10-[14C]-formyltetrahydrofolate except also contained 0.83 mM (+)-L-5-formyltetrahydrofolate. Incubation mixture contained 17 µg of S-100 protein in each case.
Fig. 4. Kinetics of fMet-tRNA formation catalyzed by S-100 from S. faecalis R grown on a medium lacking folic acid but supplemented with L-serine, L-methionine, thymine, guanine and adenine. A, B, and C as in Fig. 3. Incubation mixture contained 13 μg of S-100 protein in each case.

Fig. 5. Kinetics of fMet-tRNA formation catalyzed by S-100 from E. coli A10. A, B, and C as in Fig. 3. Incubation mixture contained 4 μg of S-100 protein in each case.

Fig. 6. Kinetics of fMet-tRNA formation with [14C]formate as donor. The standard incubation mixture was used as described under "Experimental Procedure." A (O-O), S-100 (68 μg of protein) prepared from S. faecalis R grown in medium containing folic acid; B (△-△), S-100 (104 μg of protein) from S. faecalis R grown in medium supplemented with L-serine, L-methionine, thymine, guanine, and adenine.

Fig. 7. Dependence of fMet-tRNA formation on amount of S-100 present in reaction mixture with [14C]formate as the formyl donor. The standard incubation mixture as described under "Experimental Procedure" was used. The reaction mixture was incubated for 30 min at 37°C. A (O-O), S-100 prepared from S. faecalis R grown with folic acid; B (△-△), S-100 prepared from S. faecalis R grown in folate-deficient medium supplemented with L-serine, L-methionine, thymine, guanine, and adenine. The protein concentration of the S-100 preparations used in both cases was 1.7 mg per ml.

At 37°C. Treatment of the reaction mixture with Tris-acetate at pH 8.0 under the conditions described by Sarin and Zamecnik (41) for the hydrolysis of the aminoacyl-tRNA bond without simultaneous destruction of the tRNA resulted in the solubilization of 99% of the counts, indicating that the [14C]formyl group was attached to an amino acid residue. Formation of the radioactive product was dependent upon the presence of both L-methionine and tRNA in the standard assay as described under "Experimental Procedure." No labeled product was formed when the S-100 fraction was omitted or boiled before use in the standard assay.

The S-100 fraction prepared from S. faecalis R grown in medium containing folic acid catalyzed the transfer of formyl groups from [14C]formyltetrahydrofolate to Met-tRNA^Met as shown in Fig. 3. The reaction was not inhibited by [14C]formate but was slightly inhibited by tetrahydrofolate (Fig. 3). Similar re-
results were obtained with S-100 fractions of *S. faecalis* R grown in medium lacking folic acid but supplemented with L-serine, L-methionine, thymine, adenine, and guanine (Fig. 4). This reaction was likewise not inhibited by [$\text{^1^4C}$]formate but was slightly inhibited by tetrahydrofolate (Fig. 4). The results obtained with S-100 supernatant preparations of *E. coli* A19 are shown in Fig. 5. [$\text{^1^4C}$]Formate did not inhibit the formlation of Met-tRNA$_{\text{Met}}$ with 10-$\text{[^1^4C]}$formyltetrahydrofolate as the formyl donor, but tetrahydrofolate did strongly inhibit the formation of fMet-tRNA$_{\text{Met}}$ by *E. coli* A19 S-100 (Fig. 5). The formlation of Met-tRNA$_{\text{Met}}$ with 10-[$\text{^1^4C}$]formyltetrahydrofolate was linear with respect to the amount of *S. faecalis* R or *E. coli* A19 S-100 protein present in the reaction mixture.

**Transformation with Formate**—The ability of extracts of *S. faecalis* R grown in the presence and in the absence of folate to catalyze the transformation reaction with [$\text{^1^4C}$]formate as the formyl donor was also determined. The reaction under these conditions is dependent upon the presence of endogenous tetrahydrofolate, formyltetrahydrofolate synthetase, methionyl-tRNA synthetase, ATP, and the 10-formyltetrahydrofolate: methionyl-tRNA$_{\text{Met}}$ transformylase for the transformation reaction. Under these conditions, the S-100 preparation from *S. faecalis* R grown with foalate catalyzed the formation of fMet-tRNA$_{\text{Met}}$ from the [$\text{^1^4C}$]formate (Fig. 6). The reaction was dependent upon the amount of S-100 preparation used but exhibited autocatalytic behavior at low enzyme levels (Fig. 7). The reaction was linear with respect to enzyme concentration over a narrow range of enzyme concentrations.

The S-100 preparation obtained from *S. faecalis* R grown in the absence of folic acid in a medium supplemented with L-serine, L-methionine, adenine, guanine, and thymine was not capable of catalyzing the transformation reaction with [$\text{^1^4C}$]formate under comparable conditions (Figs. 6 and 7). However, upon addition of tetrahydrofolate to the incubation mixture, S-100 extracts prepared from *S. faecalis* R cells grown on folate-free medium catalyzed the formation of [$\text{^1^4C}$]formyl-Met-tRNA$_{\text{Met}}$ with [$\text{^1^4C}$]formate as the formyl donor (Fig. 8).

The formlation of Met-tRNA$_{\text{Met}}$ by S-100 preparation of *S. faecalis* R cells grown on medium containing folic acid was not inhibited, but was rather slightly stimulated by the addition of an equal amount of S-100 from cells grown on medium lacking folic acid (Table I), thus establishing that this S-100 fraction does not contain an inhibitor that interferes with fMet-tRNA$_{\text{Met}}$ formation by the S-100 fraction prepared from cells grown without folate.

Control experiments carried out with S-100 preparations of *E. coli* A19 demonstrated that transformation occurred in the absence of added tetrahydrofolate with this extract when [14C]formate was supplied as the formyl donor.

**DISCUSSION**

Previous work has shown that the folic acid requirement of *S. faecalis* R may be replaced by supplementing the growth medium with a mixture of substances that are now recognized to be products of biosynthetic reactions in which folic acid functions as a cofactor. Microbiological assay of cells grown in the absence of folic acid, with these supplements, failed to detect the presence of any folate (28, 32), suggesting that *S. faecalis* R cannot synthesize folic acid *de novo*. In experiments reported here, it is shown that the growth rate of the organism on the folate-free medium is somewhat less than on a medium containing folic acid, but that comparable cell yields are obtained on both media. Therefore, in view of the role of 10-formyltetrahydrofolate in the Met-tRNA$_{\text{Met}}$ transformylase reaction to yield fMet-tRNA$_{\text{Met}}$, and the role of this material in the initiation of polypeptide chain biosynthesis in bacteria, it seemed as if *S. faecalis* R might provide an interesting exception to the generally accepted mechanism for initiation of protein biosynthesis in bacteria.

Evidence for the complete absence of folate in *S. faecalis* R cells has been further substantiated by demonstrating that cells grown in the absence of folic acid by the addition of various metabolic supplements are resistant to the folic acid analogues trimethoprim and aminopterin. However, these analogues inhibit
growth of S. faecalis R in the absence of the supplements when the addition of folate acid is required. The growth of E. coli, under conditions in which it is synthesizing folate, is inhibited by trimethoprim and aminopterin (4). If the transfer of the formyl group from 10-formyltetrahydrofolate to Met-tRNA^Met was necessary for the initiation of protein biosynthesis in S. faecalis R, both trimethoprim and aminopterin would have been expected to cause a decrease and ultimate cessation in growth.

The present investigation indicates that 10-formyltetrahydrofolate: methionyl-tRNA transformylase is a constitutive enzyme with respect to folate in S. faecalis R, because essentially equal transformylase activity was observed with 10-formyltetrahydrofolate as the formyl donor in S-100 preparations of cells grown on media either supplemented with or deficient in folate acid.

The observation that folate-free cells of S. faecalis R grow at a rate comparable to that of folate-sufficient cells, yet fail to form fMet-tRNA^Met when formate is utilized as the source of the formyl group, indicates that the formylation of Met-tRNA by the recognized transformylase reaction from 10-formyltetrahydrofolate is not required for initiation of polypeptide chain biosynthesis in this organism, thus suggesting that formylation of Met-tRNA may not even be required for initiation of protein biosynthesis under these conditions. The addition of exogenous tetrahydrofolate leads to the formation of fMet-tRNA by these extracts. However, the activity observed upon the addition of tetrahydrofolate to the incubation mixture for the incorporation of [14C]formate into Met-tRNA is somewhat lower than the activity observed utilizing endogenous tetrahydrofolate with S. faecalis R S-100 supernatant preparation of cells grown on medium containing folate acid. This difference in activity may be caused by a combination of two effects: slight inhibition of the transformylase by the added tetrahydrofolate and a partial repression of the 10 formyltetrahydrofolate synthetase activity by the metabolites used to replace the folate acid in the growth of the S. faecalis R cells. The transformylase activity of the S-100 preparation of S. faecalis R cells grown on medium containing folate acid was not inhibited by the addition of an equal amount of S-100 prepared from cells grown on medium lacking folate acid, thus establishing that the S-100 preparation of non-folate cells does not contain a substance that inhibits its transformylase activity.

In contrast to the results reported by Dickerman and Smith (42) showing that tetrahydrofolate is an effective competitive inhibitor of E. coli B transformylase, which was confirmed in experiments reported here on E. coli A19 (transformylase, the transformylase present in the S-100 preparation derived from S. faecalis R grown either with folate or with supplements was inhibited only slightly by tetrahydrofolate. The significance of this observation is not completely understood at the present time.

The results presented here indicate that fMet-tRNA^Met may not be involved in the initiation of protein synthesis in S. faecalis R when grown in a folate-free medium. However, it is also possible that formylation of the Met-tRNA^Met may occur with or without the enzyme other than 10-formyltetrahydrofolate and its specific transformylase. The experiments described in this study indicating that [14C]formate is not converted to the second formyl group from fMet-tRNA^Met by extracts of folate-free S. faecalis R cells do not altogether eliminate such a possibility, because it is possible that the enzyme catalyzing this alternative transformylation reaction is unstable under the experimental conditions used or that the added [14C]formate is not in equilibrium with an endogenous formyl donor.

The possibility that initiation of protein biosynthesis in prokaryotes may not in all cases necessarily involve formylated Met-tRNA^Met also deserves consideration in view of observations indicating that fMet-tRNA^Met is not converted to the initiation site on the 30 S ribosomal subunit might also be operative under certain conditions in S. faecalis R, a 70 S ribosomal system.

Acknowledgment—We are indebted to Dr. Richard H. Himes for helpful discussions.

REFERENCES
Evidence against the Folate-mediated Formylation of Formyl-accepting Methionyl Transfer Ribonucleic Acid in *Streptococcus faecalis R*
Charles E. Samuel, Linda D’Ari and Jesse C. Rabinowitz


Access the most updated version of this article at http://www.jbc.org/content/245/19/5115

Alerts:
- When this article is cited
- When a correction for this article is posted

Click here to choose from all of JBC’s e-mail alerts

This article cites 0 references, 0 of which can be accessed free at http://www.jbc.org/content/245/19/5115.full.html#ref-list-1