cAMP Stimulation of Dictyostelium discoideum Destabilizes the mRNA for 117 Antigen*

(Received for publication, December 19, 1989)

Maria Helena Juliani†‡§, Gláucia Mendes Souza‡‖, and Claudette Klein†**
From the †Departmento de Bioquimica, Instituto de Quimica, Universidade de Sao Paulo, Caixa Postal 20780, Sao Paulo 01498, Brasil and the ‡Edward A. Doisy Department of Biochemistry and Molecular Biology, St. Louis University School of Medicine, St. Louis, Missouri 63104

Transcription of the 117 gene and changes in its mRNA levels in Dictyostelium discoideum were studied by mRNA hybridization with a cDNA probe. In wild type cells (Ax-2), the expression is developmentally regulated during cell aggregation, while in the aggregateless mutant, Agip 45, 117 mRNA is not detectable during cell starvation. Low concentrations of cAMP, given in the form of extracellular pulses to induce the development of starved Agip 45 cells to aggregation competence, are able to induce the appearance of 117 mRNA. The induction seems to be via the cell surface cAMP receptor and by a mechanism which does not involve changes in intracellular cAMP. Interestingly, high concentrations of cAMP, which downregulate the cell surface cAMP receptor, elicit a rapid decrease in the level of 117 mRNA in aggregation-competent cells. Nuclear run-on and pulse-chase experiments show that the high concentrations of cAMP selectively destabilize the mRNA for 117 antigen. This destabilization requires both de novo mRNA synthesis and protein synthesis since the addition of inhibitors of these processes eliminates the effects of cAMP on 117 mRNA. The data suggest that a cAMP-induced protein(s) may be involved in the destabilization of selective mRNAs.

In a number of cases, changes in intracellular cAMP levels are associated with altered gene expression in eukaryotes, but the mechanism(s) by which cAMP affects gene activity is poorly understood. Promoter regions of an increasing number of cAMP-regulated genes have been isolated and characterized to define cAMP-regulatory elements (1). Although the possibility exists that cAMP controls mRNA stability (2), this has not been extensively documented experimentally.

* This research was supported by research grants GM 34561 from the National Institutes of Health and DCB 8603584 from the National Science Foundation (to C. K.) and a Financiadora de Estudos e Projetos (Brazil) grant (to M. H. J.). The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked "advertisement" in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.
† This paper is dedicated to the memory of Dr. Juliani who recently passed away.
‡ Held a fellowship from Fundacao de Amparo a Pesquisa do Estado de Sao Paulo (FAPESP) during the initial portion of the work.
§ Recipient of an undergraduate fellowship from FAPESP.
** To whom correspondence and reprint requests should be addressed: Edward A. Doisy, Dept. of Biochemistry and Molecular Biology, St. Louis University School of Medicine, 1402 S. Grand Blvd., St. Louis, MO 63104.

The phosphoenolpyruvate carboxykinase (GTP) mRNA has been reported to be stabilized by cAMP (3). More generally, cAMP appears to alter the rate of gene transcription. Some genes are rapidly regulated by cAMP in a manner that seems to be insensitive to cycloheximide (4). Other classes of genes are induced only after several hours of cAMP treatment, a period that probably suggests the need for continued protein synthesis (1). The distinction of genes transcriptionally activated by cAMP by the requirement for protein synthesis would be similar to that made in the case of steroid hormone induced primary and secondary responses (5).

For Dictyostelium discoideum, extracellular cAMP has been shown to play an important role in development, while little is known about its possible intracellular effects. Extracellular cAMP pulses function as a chemoattractant during cell aggregation (6) as well as an effector of cell differentiation to aggregation competence (7). The effects of extracellular cAMP are mediated by a cell surface cAMP receptor which shows a number of similarities to mammalian hormone receptors including ligand-induced phosphorylation (8, 9) and down-regulation (10). During aggregation, cAMP pulses effect the mRNA levels of certain developmentally regulated genes and pharmacological studies suggest that these effects are mediated by the cell surface cAMP receptor (11–14). In the cases studied, cAMP alters the rate of gene transcription (15–17) and acts additionally to stabilize developmentally regulated mRNAs (18, 19). Upon disaggregation of post-aggregative cells, many of the developmentally increased mRNAs disappear. The addition of cAMP to cells at the time of disaggregation restores many of those mRNAs, primarily by restoring their rates of transcription (18), but also by preventing the destabilization of labile mRNAs (19).

We have previously demonstrated that 117 antigen is expressed cyclically during the development of D. discoideum. Both cell surface protein and mRNA levels are nondetectable in vegetative cells, maximal in aggregating cells, and then return to nondetectable levels as cells form slugs. Latter in development, as slugs begin to culminate, 117 protein and mRNA reappear as prespore cells differentiate into spores. Both are then lost as cells complete their differentiation into mature spores (20, 21). To begin to understand the factors that regulate the expression of 117 antigen, we have examined the effects of cAMP stimulation on 117 mRNA levels. We show here that cAMP pulses can induce 117 mRNA in cells, while high concentrations of cAMP result in a rapid loss of that message. Using pulse-chase and nuclear run-off assays, combined with inhibitors of RNA and protein synthesis, we examined the basis for the effects of high concentrations of cAMP. The data indicate that stimulation of cells with high concentrations of cAMP destabilizes the 117 mRNA and does so by a mechanism requiring protein synthesis.
**EXPERIMENTAL PROCEDURES**

*Cell Culture Conditions—* Ax-2 (wild type) amoebae (22) and the mutant Agip 45 (23) were grown in HL-5 medium (24). Development was initiated by washing cells with 20 mM MES, pH 6.4, 1 mM MgCl₂, and resuspending them in that buffer at a density of 10⁶ cells/ml. Cells were starved as spinner suspensions and their development to aggregation competence monitored microscopically as described (25). With wild-type cells, this occurs after 5-6 h of starvation. Agip 45 does not develop aggregation competence when placed under starvation conditions unless pulsed with cAMP (23). To do so, cells were starved for 2 h and then pulsed with 10⁻² M cAMP at 5-min intervals as described previously (7, 23).

*RNA isolation and Northern Transfer—* Total RNA was isolated according to a simplified procedure developed by H. Sadeghi in our laboratory. Approximately 10⁶ cells were harvested by centrifugation and resuspended in cold phosphate buffer, pH 6.4, 1 mM MgCl₂, and resuspending them in that buffer for 45 min. Experiments have indicated that after that period, no increase of radiolabel into whole cell RNA occurs (31). Hybridization to excess B-17 plasmid was used to verify that no further radiolabeling of 117 mRNA occurred. At that time, 1 mM cAMP was added to one-half of the culture. Aliquots of cells were withdrawn at the indicated times for RNA isolation. A constant mass of ³²P-labeled RNA (60 µg) was hybridized to immobilized plasmids as described above.

*Materials—* Radioucleotides were purchased from ICN Radiochemicals. [α-³²P]dATP and [α-³²P]UTP were also prepared by the method of Walseth and Johnson (32). Paclitaxel and nogalamycin were the generous gifts of Donald E. Harper, The Upjohn Co., Kalamazoo, MI. Dr. Richard Firtel kindly provided us with the actin B-1 plasmid. All other chemicals were from Sigma.

**RESULTS**

*Induction of 117 mRNA by cAMP Pulses—* To examine the effects of cAMP pulses on 117 mRNA levels, we made use of the aggregation-minus mutant Agip 45. Since these cells are unable to synthesize pulses of cAMP when placed under starvation conditions, we could readily examine the effects of exogenous pulses (23). When Agip 45 cells were starved for increasing periods of time in the absence of pulse treatment, little 117 mRNA was detected (Fig. 1A, lanes 1-5). If Agip 45 cells were starved and treated with cAMP pulses, 2 h of such treatment was sufficient to induce 117 mRNA (lane 6). It should be noted that pulse treatment is initiated 2 h after starvation. Thus, 2 h of such treatment corresponds to a total of 4 h of starvation. Maximum levels of 117 mRNA were present after 6 h of pulse treatment (lane 8), a total starvation time corresponding to 8 h. The time course of accumulation of 117 mRNA in pulsed, Agip 45 cells is similar to that seen in Ax-2 cells, in which pulses of cAMP are spontaneously generated (Fig. 1B).

Although these results indicate that the level of 117 mRNA is induced by cAMP pulses, we do not know if this is a direct, or indirect effect. Since cAMP pulses stimulate the development of cells to aggregation competence, we could expect that the expression of any developmentally regulated component during this period would be enhanced. We have determined, however, that intracellular cAMP does not appear to be

1 The abbreviations used are: MES, N-(2-hydroxyethyl)piperazine-N-2-ethanesulfonic acid; SDS, sodium dodecyl sulfate; Hepes, N-2-hydroxyethylpiperazine-N-2-ethanesulfonic acid.
required for the changes in 117 mRNA. This was explored by starving cells in the presence of 5 mM caffeine, which is known to inhibit the cAMP-induced activation of adenylate cyclase in *D. discoideum* and hence inhibit changes in intracellular cAMP (13, 14, 33). Fig. 2 shows that when cells are starved in the presence of caffeine, no changes in 117 mRNA levels are observed over time (lanes 1–5). As caffeine-treated cells do not synthesize cAMP, they are unable to produce external cAMP pulses. If such cells are supplied with exogenous pulses of cAMP, significant levels of 117 mRNA accumulate (lanes 6–8). The data suggest that while external cAMP pulses can promote the accumulation of 117 mRNA, intracellular cAMP is not required for this process.

**Down-regulation of the cAMP Receptor Results in a Loss of 117 mRNA**—The effects of high concentrations of cAMP on 117 mRNA levels were examined. We have previously demonstrated that stimulation of cells with 1 mM cAMP leads to a rapid down-regulation of the cAMP receptor, such that by 30 min cells have lost approximately 80–85% of their binding sites (10). As shown in Fig. 3, when 6-h starved cells were treated with 1 mM cAMP, the level of 117 mRNA decreased such that by 30 min of such treatment, cells contained approximately 10% of the message present in untreated control cells (also see Fig. 8). This decrease in 117 mRNA levels did not reflect a general cellular change since the levels of actin mRNA were not affected under these conditions (data not shown).

To assess if the effects of high concentrations of cAMP on 117 mRNA levels were the result of receptor down-regulation, we performed similar experiments using a range of concentrations of two cAMP analogues. 2′-Deoxy-cAMP is a potent agonist for the cAMP cell surface receptor, but has a very weak ability to activate the cAMP-dependent protein kinase. Dibutyryl cAMP shows the opposite specificity (34, 12). As shown in Fig. 4, dibutyryl cAMP treatment of cells, at any of the concentrations tested, had little or no effect on the level of 117 mRNA. In contrast, 2′-deoxy-cAMP treatment resulted in a dramatic decrease in 117 mRNA levels and its effects exhibited a dose dependence similar to that of cAMP treatment. The results indicate that the effects of high concentrations of cAMP on mRNA 117 are also mediated by the cell surface cAMP receptor.

Nuclear run-off transcription assays were employed to determine if the decrease in 117 mRNA levels elicited by high doses of cAMP was due to an arrest of gene transcription. In these experiments, transcription from nuclei isolated from 6-h starved cells that had been incubated for 30 min in the absence of presence of 1 mM cAMP were compared. As shown in Fig. 5, no obvious decrease in the level of 117 mRNA transcription was observed in nuclei from cells that had, or had not, been treated with high concentrations of cAMP. As expected, such nuclei synthesized equivalent amounts of actin mRNA, a gene unaffected by cAMP (35). No detectable 117 mRNA was synthesized by nuclei isolated from vegetative cells, consistent with the fact that vegetative cells do not accumulate detectable 117 mRNA. Thus, the developmental increase in this mRNA reflects changes in gene transcription. The data indicate that treatment of cells with high concentrations of cAMP alters 117 mRNA levels, not by arresting

**Fig. 2. Effect of caffeine on 117 mRNA expression.** Ax-2 amoebae were starved in the presence of caffeine (initially added at 5 mM and then hourly additions at 2 mM). After the first 2 h of starvation, one-half of the population was pulsed with cAMP (lanes 6–8). 117 mRNA levels were determined by Northern analysis. Times of starvation were 0 h (lane 1), 2 h (lane 2), 4 h (lanes 3 and 6), and 6 h (lanes 4 and 7), and 8 h (lanes 5 and 8). The picture is one autoradiogram in which intervening lanes have been removed. The data are representative of three experiments.

**Fig. 3. Stimulation of cells with high concentrations of cAMP decreases 117 mRNA levels.** Ax-2 cells were starved for 6 h and half of the population was then stimulated with 1 mM cAMP. The levels of 117 mRNA present in cells determined at the indicated min after cAMP addition: 1 (lane 1) 5 (lane 3), 15 (lane 5), 30 (lane 7), 45 (lane 9), and 60 (lane 10). Even-numbered lanes 2–8 represent the level of 117 mRNA present in cells which had not been treated with cAMP but incubated for the additional 5–45 min. The data are representative of four experiments.

**Fig. 4. Cell treatment with cAMP analogues.** Ax-2 cells were starved for 6 h at which time cAMP, 2′-deoxy-cAMP, or dibutyryl cAMP was added. Cells were starved for an additional 30 min and then incubated for the additional 30 min in the absence of any treatment. The picture represents one autoradiogram from which individual lanes were cut and repositioned for ease of discussion. A significant gradation in the background across the filter occurred and is accentuated by the repositioning of the lanes. The data are representative of three experiments.
Destabilization of mRNA by cAMP

Fig. 5. 117 mRNA transcription in response to cAMP stimulation. 6-h starved Ax-2 cells were incubated in the absence (−) or presence (+) of 1 mM cAMP for 30 min. At that time, nuclei were isolated and run-off transcription assayed as described under "Experimental Procedures." Nuclei from vegetative amoebae (V) were also analyzed. Transcripts were hybridized to varied amounts of either the Bluescribe plasmid without any insert (plasmid) or to the plasmid containing a cDNA insert for actin or 117, respectively. From top to bottom, the amounts of DNA immobilized onto the filter were 5, 2.5, 0.1, and 0.01 μg. The data are representative of five experiments.

Fig. 6. Pulse-chase analysis of 117 mRNA. Ax-2 amoebae were starved for 6 h, pulse-labeled with 32P orthophosphate for 1.5 h, and placed in the chase medium for 45 min. 1 mM cAMP was then added to one-half of the population. RNA was extracted and hybridized to 5, 2.5, and 1 μg of immobilized plasmid containing the 117 cDNA (top filters). Alternatively, samples were hybridized to the B-1 actin plasmid (time 0 and 45 min) or to plasmid alone (times 15, 30, and 60 min) (bottom filter). The autoradiogram showing hybridization to the B-1 plasmid was exposed for a shorter period to provide signal intensities similar to that observed with the plasmid containing the 117 cDNA. The data are representative of five experiments.

its synthesis but more likely by enhancing its degradation.

This hypothesis was substantiated by measuring 117 mRNA stability using pulse-chase analysis. Cells were labeled with 32P orthophosphate for 1.5 h and then incubated in phosphate buffer for 45 min. At that time, one-half of the cells were stimulated with 1 mM cAMP and after varied times, were examined for their levels of radioactive 117 mRNA. As seen in Fig. 6, cells that had been treated with cAMP showed an accelerated degradation of 117 mRNA compared to untreated cells. In the absence of cAMP treatment, only a slight decrease in radio-labeled 117 mRNA was observed during the 60-min chase period. In contrast, that level was dramatically reduced in CAMP-stimulated cells. In the first 15-min incubation of cells with cAMP, the decrease in radioactive 117 mRNA was slight. During the subsequent 15 min, the major loss in radioactive 117 mRNA occurred. After this time only slight decreases in radioactive 117 mRNA were observed. The effect of cell incubation with cAMP on 117 mRNA stability was not a general one. The level of radiolabeled actin mRNA remained relatively constant during this chase period, as previously reported (31) and was not affected by CAMP stimulation of cells.

Destabilization of 117 mRNA Requires RNA and Protein Synthesis—The above experiments indicate that CAMP stimulation of cells results in an enhanced degradation of 117 mRNA. To determine if this is a primary effect, or one that requires new protein synthesis (secondary effect), we examined 117 mRNA stability in cells treated with inhibitors of RNA or protein synthesis. Inhibition of RNA synthesis was accomplished using a mixture of actinomycin D and daunomycin (18). Fig. 7A shows that the decrease in 117 mRNA in the presence of 1 mM cAMP (+) was largely prevented when RNA synthesis was inhibited. To eliminate the possibility that the inhibitors themselves were stabilizing the message to the effects of CAMP, we also performed these experiments using nogalamycin. This RNA synthesis inhibitor has been used in D. discoideum to determine mRNA half-lives in germinating spores (36). The same results were obtained (Fig. 7B).

The inability of CAMP stimulation to alter 117 mRNA stability in the above experiments suggests that RNA synthesis is required for that to occur. A newly synthesized RNA may itself act to destabilize 117 mRNA or it may encode a protein that does so. In accordance with the latter interpretation, the addition of protein synthesis inhibitors prevented the CAMP-induced loss of 117 mRNA (Fig. 8). In the experiment shown, pactamycin was added to cells and, after a 30-min incubation, CAMP was added to one-half the culture. Also shown are the results obtained when cells which had not been incubated with pactamycin were stimulated with CAMP. In the presence of pactamycin, CAMP treatment did not alter the levels of 117 mRNA. Similar results were obtained when the experiment was performed using cycloheximide to inhibit protein synthesis (data not shown). It would appear that...
protein synthesis is required for cAMP stimulation to destabilize 117 mRNA. It should be noted that although cAMP stimulation no longer altered the level of 117 mRNA, a decrease in that level was observed over the course of the experiment when cells were incubated with the inhibitors. This may indicate that protein synthesis is also necessary for maintaining 117 mRNA levels.

**DISCUSSION**

Our previous experiments have shown that cell stimulation with high concentrations of cAMP results in a loss of cell surface cAMP receptor sites (10). Incubation of cells with 0.1 mM cAMP for 30 min results in an approximate 70% loss of receptor binding activity on the cell surface while 1 mM cAMP can induce an almost 100% loss of receptors. The need for such high concentrations of cAMP reflects the activity of the extracellular phosphodiesterase which severely restricts the lifetime of the added cAMP. Much lower concentrations of cAMP effectively induce receptor down-regulation in the phosphodiesterase mutant (37). The mechanism of this down-regulation is not clear but may involve the phosphorylation of the cAMP receptor (8, 9, 38) and the formation of a slowly dissociating form of the receptor (37). Here we have demonstrated that conditions which lead to receptor down-regulation result in decreased levels of 117 mRNA. Stimulation of cells with dibutyryl cAMP, which is a poor agonist for the cAMP receptor but which can permeate cells and activate the intracellular cAMP-dependent protein kinase (12, 34), was not an efficient effector of 117 mRNA levels. In contrast, 2-deoxy-cAMP, which has a high affinity for the cell surface receptor and elicits its down-regulation, but binds poorly to the cAMP-dependent protein kinase (94), showed effects similar to those of cAMP.

The above observations would also argue that changes in intracellular cAMP are not necessary for the decrease in 117 mRNA that occurs when cells are incubated with high concentrations of cAMP. Similarly, the increase in 117 mRNA levels by pulsing cells with low concentrations of cAMP was shown not to require changes in intracellular cAMP. Thus, although both of these phenomena are mediated by the cAMP surface receptor, it would appear that receptor coupling to, and subsequent activation of, adenylate cyclase is not the mechanism by which these events occur. Other second messengers like Ca++ or diacetyl glycerol, or cGMP may be involved in increasing 117 mRNA levels in response to cAMP pulses since such receptor activation appears to be linked also to inositol triphosphate production, changes in Ca++ concentrations, and guanylate cyclase activation (39, 40). It is not yet known if these changes also accompany the receptor down-regulation response that is associated with the decrease of 117 mRNA when cells are incubated with high cAMP concentrations.

A number of laboratories have investigated the effects of cAMP on specific mRNA levels at different developmental stages (11–19). Predominantly, those studies have documented changes in gene transcription (15–18) or enhanced mRNA stability (19). The data presented in this paper describe a different effect of cAMP. They show that events mediated by the cAMP surface receptor result in a destabilization of an mRNA. Three lines of evidence were obtained to support this conclusion: Cells that were incubated with cAMP showed a relatively rapid decrease in their level of 117 mRNA, but retained normal levels of the actin mRNA. The rate of transcription of the 117 gene, as determined from nuclear run-off assays, was not reduced by treating cells with this concentration of cAMP. Also, pulse-chase experiments indicated that such treatment lead to an enhanced rate of degradation of the 117 message. It should also be noted that this destabilization of 117 mRNA was observed after approximately 15 min of cell exposure to cAMP. This was observed in both the experiments measuring changes in cellular 117 mRNA levels in response to cAMP stimulation and in the pulse-chase analyses. This period could reflect the time necessary to synthesize a protein(s) that influences 117 mRNA stability. Such an hypothesis is supported by the observation that inhibitors of either RNA or protein synthesis blocked the effect of cAMP stimulation of 117 mRNA levels.

Each of the two inhibitors of protein synthesis used in this investigation has a distinct mode of action. Cycloheximide inhibits the elongation step of protein synthesis while pactamycin inhibits the formation of the initiation complex. Consequently, polysomes accumulate or break down under these respective treatments. Kelly et al. (41) have shown that some mRNAs may be stabilized by cycloheximide but not affected by pactamycin treatment. Since both of these drugs prevented the cAMP-induced decrease in 117 mRNA levels, it is unlikely that such levels reflect the state of polysomes after inhibition of protein synthesis. Taken together, the data support the hypothesis that cAMP stimulation induces the expression of an mRNA destabilizing protein. A similar hypothesis has been presented to explain the glucocorticoid-enhanced destabilization of interleukin-1b mRNA in human cell lines and the requirements for protein synthesis for this to occur (42).

We have also observed that although cAMP could no longer stimulate 117 mRNA decay in cells incubated with cycloheximide or pactamycin, the rate of loss of the mRNA was faster when these drugs were present (but never as great as with cAMP treatment alone). The meaning of this is as yet unclear but may suggest that ongoing protein synthesis is also required for the stabilization of 117 mRNA.

It is a rather unusual finding that the same compound (cAMP) can elicit two opposing processes, depending upon the manner the stimulus is presented to the cells. Low doses, in the form of pulses, result in increased levels of 117 mRNA, a probable reflection of enhanced transcription. Higher doses of cAMP elicit a rapid loss in 117 mRNA, a result of mRNA destabilization. This dual regulation of 117 mRNA by cAMP, however, correlates well with the events that accompany the development of the amoebae. During the initial phase of the developmental cycle, 117 mRNA increases as cells produce cAMP pulses and develop aggregation competence. Nuclear run-off experiments indicated that this rise in mRNA levels reflects changes in gene transcription. When cells terminate their aggregation program and begin to form slugs, 117 mRNA is not detectable (21, 28). During this transition stage, the cell surface levels of the cAMP receptor also decrease (43, 10). It is possible that this decrease reflects the down-regulation of receptors induced by the high external cAMP concentrations in the micro-environment of the receptor (10). Thus, the events we have associated with the destabilization of 117 mRNA, receptor down-regulation and new protein synthesis leading to 117 mRNA degradation, may underlie the loss of 117 mRNA seen at this developmental period. As mentioned earlier, 117 mRNA reaccumulates later in development, during culmination, and then disappears as mature fruiting bodies are formed (20, 21). Although a role for cAMP has not been established for cells at this stage in development, it is intriguing to imagine that 117 mRNA is regulated in a manner similar to that seen during aggregation. Continued investigations should identify the mechanism by which cAMP elicits mRNA degradation, the intermediate gene products involved,
and the role of this phenomena in the biogenesis of a multicellular organism:

Acknowledgments—We wish to thank Dr. Daphne Blumberg (University of Maryland) for her evaluation of this manuscript, Dr. David Soll and B. Kraft (University of Iowa) for sharing their insights into performing nuclear run-off experiments, Mario Lopes Duarte (São Paulo) for the synthesis of [cr-32P]UTP and [a-32P]dATP, and Marcia Quint (St. Louis University) for the typing of this manuscript.

Note Added in Proof—In the course of this work, experiments done in collaboration with Dr. G. Gerisch (Max-Planck-Institut) have indicated that 117 antigen and csA are similar, if not identical, 25.

REFERENCES
1. Roccel, W. J., Vandenbork, G. R., and Hanson, R. W. (1988) J. Biol. Chem. 263, 9063-9066
2. Brawer, M. C. (1987) Cell 48, 5-6
3. Hul, Y., and Hamsra, R. W. (1988) J. Biol. Chem. 263, 7747-7752
4. Sasski, K., Cripe, T. P., Koch, S. R., Andreone, T. L., Petersen, D. D., Beale, E. G., and Granners, D. K. (1984) J. Biol. Chem. 259, 15424-15521
5. Yamamoto, K. R. (1985) Annu. Rev. Genet. 19, 209-215
6. Bonner, J. T. (1967) The Cellular Slime Molds, 2nd Ed., Princeton University, Princeton, NJ
7. Darmon, M., Brachet, P., and da Silva, L. H. (1975) Proc. Natl. Acad. Sci. U. S. A. 72, 2180-2184
8. Lubs-Haukeness, J., and Klein, C. (1982) J. Biol. Chem. 257, 12204-12208
9. Meier, K., and Klein, C. (1988) Proc. Natl. Acad. Sci. U. S. A. 85, 2181-2185
10. Klein, C., and Juliani, M. H. (1979) Cell 19, 343-347
11. Haribabu, B., and Dottin, R. P. (1986) Mol. Cell. Biol. 6, 2402-2408
12. Osawa, M., and Blumberg, D. D. (1986) Proc. Natl. Acad. Sci. U. S. A. 83, 4819-4823
13. Mann, S. K. O., and Firtel, R. A. (1987) Mol. Cell. Biol. 7, 458-469
14. Kimmel, A. R. (1987) Dev. Biol. 122, 163-171
15. Driscoll, D. M., and Williams, J. G. (1987) Mol. Cell. Biol. 7, 4482-4489
16. Williams, J. G., Tsang, A. S., and Mahbubani, H. (1980) Proc. Natl. Acad. Sci. U. S. A. 77, 7171-7175
17. Landfair, S. M., Lefebvre, P., Chung, S., and Lodish, H. F. (1982) Mol. Cell. Biol. 2, 1417-1426
18. Chung, S., Landfair, S. M., Blumberg, D. D., Cohen, N. S., and Lodish, H. F. (1981) Cell 24, 785-787
19. Mangiarotti, G., Ceccarelli, A., and Lodish, H. F. (1983) Nature 301, 616-618
20. Sadeghi, H., Williams, K., and Klein, C. (1987) J. Biol. Chem. 262, 16294-16299
21. Browne, L. H., Sadeghi, H., Blumberg, D., Williams, K. L., and Klein, C. (1989) Development 105, 657-664
22. Watts, D. J., and Ashworth, J. M. (1970) Biochem. J. 119, 171-174
23. Darmon, M., Barraud, P., Broschet, P., Klein, C., and da Silva, L. H. (1977) Dev. Biol. 58, 174-184
24. Sussman, M. (1966) in Methods in Cell Physiology (Prescott, D. D., ed), pp. 397-410, Academic Press, New York
25. Juliani, M. H., Brusca, J., and Klein, C. (1981) Dev. Biol. 83, 114-121
26. Maniatis, T., Fritsch, E. F., and Sambrook, J. (1982) Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY
27. Siegel, L. I., and Bresnick, E. (1986) Annu. Rev. Biochem. 159, 82-85
28. Sadeghi, H., Silva, A., and Klein, C. (1985) Dev. Genet. 8, 561-568
29. Feinberg, A., and Vogelstein, B. (1984) Annu. Rev. Biochem. 53, 266-277
30. Soll, D. R., and Sussman, M. (1973) Biochim. Biophys. Acta 319, 312-322
31. Shapiro, R. A., Herrick, D., Manrow, R. E., Blinder, D., and Jacobson, A. (1988) Mol. Cell. Biol. 8, 1957-1969
32. Walseth, T., and Johnson, R. A. (1979) Biochim. Biophys. Acta 562, 11-31
33. Bresnack, E., and Thomas, S. D. (1984) Dev. Biol. 101, 136-146
34. Van Hasstert, P. J. M., and Klein, C. (1983) J. Biol. Chem. 258, 9636-9642
35. Kimmel, A. R., and Firtel, R. A. (1982) in The Development of Dictyostelium discoideum (Loomis, W. F., ed), pp. 233-324, Academic Press, New York
36. Kelly, R., Kelly, L. J., and Ennis, H. L. (1985) Mol. Cell. Biol. 5, 133-139
37. Klein, C. (1979) J. Biol. Chem. 254, 12573-12578
38. Klein, C., Lubs-Haukeness, J., and Simons, S. (1985) J. Cell Biol. 100, 715-720
39. Newell, P. C., Europ-Finner, G. N., Small, N. V., and Liu, G. (1988) J. Cell Sci. 99, 123-128
40. Loomis, W. F. (ed) (1982) The Development of D. discoideum Academic Press, New York
41. Kelly, R., Shaw, D. R., and Ennis, H. L. (1987) Mol. Cell Biol. 7, 799-905
42. Lee, S. W., Tsou, A., Chan, H., Thomas, J., Petrie, K., Eugui, E. M., and Allison, A. C. (1988) Proc. Natl. Acad. Sci. U. S. A. 85, 1204-1208
43. Greene, A., and Newell, P. C. (1975) Cell 6, 129-136
cAMP stimulation of Dictyostelium discoideum destabilizes the mRNA for 117 antigen.
M H Juliani, G M Souza and C Klein

J. Biol. Chem. 1990, 265:9077-9082.

Access the most updated version of this article at http://www.jbc.org/content/265/16/9077

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/265/16/9077.full.html#ref-list-1